Web Distribution of Patient Specific Measurable Arterial Models

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Abstract

In this communication a novel framework for the segmentation, 3D reconstruction and web distribution of vessel structures is presented. Deformable models are used for segmentation, VRML and ECMA scripting are used to obtain 3D models that are not only viewable from any VRML97 enabled browser, but that also allow users to interact with the model, to navigate along the vessel lumen and to perform guided measurements of distances and angles. The segmented data are automatically converted in VRML97 worlds hiding scripting code that enables the measurement of the geometrical parameters relevant for surgical planning directly from standard web browsers.
Keywords: Arterial trees, centerline, endografting, VRML

I. Web based medical data analysis

In the near future a large amount of medical data will be transmitted across Internet for remote diagnosis, electronic patient records retrieval, home care, etc. Images, annotations and texts can be easily transmitted with the standard protocols and can be viewed by medical doctors everywhere by using common web browsers and many examples of web based telemedicine have been proposed and presented in conference papers [1], [2], [3]. On the other hand, there are few examples in literature relative to the distribution via Web of 3D models of organs, even though several commonly available systems support 3D reconstruction – very often in difficult to export data format – from patient data. A few papers on web based 3D model analysis of organs have been presented, but they are usually not tailored to real clinical needs or diagnostic purposes. Typically these models are used only for qualitative study or to implement simple surgical simulators, like in John et al. [5], albeit current technology limitations force a strong simplification of the procedures being simulated. There are, however, simple applications where current 3D reconstruction and Web technologies can be harnessed to provide an useful tool for clinical use. In this communication we will describe a system that allows surgeons to quantitatively measure geometrical features of vessels for endovascular surgical planning.

The new minimally invasive endovascular surgery techniques[6] require a precise knowledge of distances, dimensions, radii and angles of the vessel region to be treated, and the traditional technique of using 2D projections to perform these measurements can lead to large errors[7]. Three dimensional models of vessels can provide surgeons with better quantitative estimates, that can be used, e.g., to measure position and size of aneurysms, to localize stenoses and plaques, and, once it is decided that surgery is necessary, to choose the most appropriate endovascular prostheses and to plan a surgical intervention.

If we consider the fact that, even if minimally invasive, these surgical procedures cause a mortality of about 1% of the patients and that prostheses are costly objects, we can understand that the development of systems enabling surgeons to quantitatively analyze 3D models of the region to be treated can be very useful, especially if these systems do not require the acquisition by the surgical unit of dedicated hardware and software and – even more important – specialized personnel.

In this communication we will report on a new system for the 3D reconstruction and distribution on the net of models for vessels structures. The system is specifically designed to support guided measurements of parameters of medical interest. Once validated, the technology described here could be used by specializes service centers to provide in a cost-effective way, surgical support through the 3D based measurements. Fig. 1 shows the expected service model: the diagnostic center can send

DICOM3 datasets through the net to the elaboration center, and after a few hours, the surgeons can browse, from their standard PC, the relative VRML97 model and perform guided measurements. Differently from other similar services currently available, this new system is based on open standard, does not require specialized software on the client side and it is specifically designed to operate within Internet.

This communication is structured as follows: section 2 presents the segmentation procedure developed to build the vessel models, section 3 describes the VRML97 conversion and the remote measurement support while the last section relates future applications and work in progress.

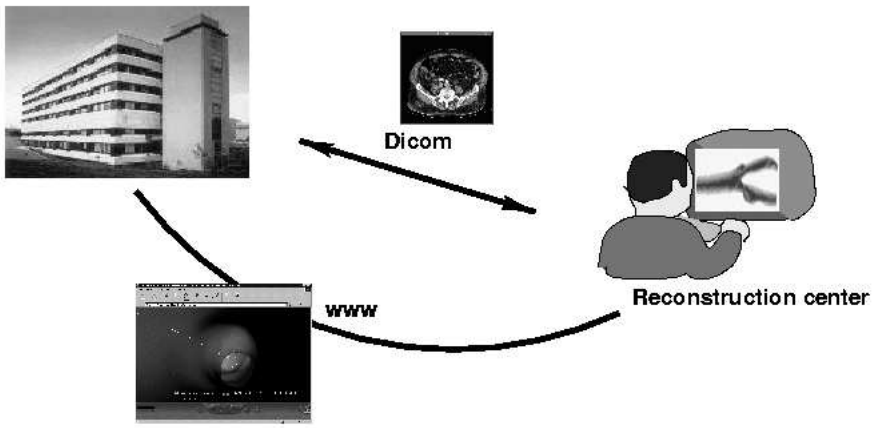

Fig. 1. The VRML97 measurable model service: a diagnostic center can send images to the reconstruction center, and a few hours after, 3D model with guided measurement support are available on the net.

II. Building an arterial tree model from CT/MR data

We work on CT and MR dataset received on our DICOM3 server. Assuming a fast network connection [4], these dataset can be directly loaded and processed by our segmentation tools a few minutes after the acquisition. In order to support the relevant measurements on vascular geometries we needed a particular structure, "Arterial Tree", for the reconstructed model containing both the complete surface mesh with no holes for the vessels internal surface, and a series of 1D lines representing the vessels centerline. This data structure and some geometrical operations on it have been realized using the XOX Shapes Microtopology libraries [13]. We have two segmentation frameworks for the arterial tree generation: from 2D contours or from direct 3D segmentation.

From 2D contours

This method consists of first generating single tubes from series of contours located in the 3D space and then joining them with basic operations. Contours are extracted from 2D slices (with arbitrary orientation) using region growing or balloon snakes [8], [9] algorithms, and can be modified and controlled through a specialize user interface. Tubes are built in the following way: first point correspondence on successive contours is set, then new points can be added if the spacing between points of the same contour and corresponding points of successive contours is not regular, finally, a triangulated surface is generated and a centerline (a spline joining the centers of mass of the contours) is also built. The operations introduced to join the contours are three: simple joint, anastomosis and bifurcation. The first connects two tubes at their extrema, the second joins two intersecting tubes, the third joins three different tubes in a bifurcation structure.

3D simplex balloon

The same procedure of the balloon evolution, can be performed directly in 3D starting from a small sphere first put inside the data set and then grown driven by an internal pressure, regularizing forces

and voxel based forces. We found a good 3D geometrical structure to be used as a basis to implement the balloon in the Simplex Meshes introduced by Delingette el al. [10]. Simplex Meshes are very simple surface meshes where each node is connected exactly to three neighbors. This makes very easy to write the code for the dynamics and the algorithms obtained are simple and fast. The only problem of this method is that the geometry obtained is composed by non planar polygons. We overcame the latter by saving for rendering the dual triangulation of the surface, obtained from nodes placed at the center of each simplex face connected with the other nodes corresponding to the neighboring faces of the simplex mesh. We implemented the internal forces to keep the balloon smooth, based on the "simplex angle continuity constraint"[10]. We then added an inflating force directed as the unit normal vector on each node and we used the two different image forces to stop the balloon inflation: a rejecting force, equal and opposite to the inflating one if the difference between the gray level of the voxel differs from the central value more then a defined threshold and an edge force attracting nodes towards brightness gradient maxima. We control the size of the faces by splitting them if they overshoot either an area or an elongation threshold and by merging them if under another threshold. If the contrast of the data is good, it is possible then to reconstruct the vessel geometry even starting the segmentation from a small sphere inside the vessel and then let it evolve until it stops growing. The Simplex balloon do not provide an Arterial Tree as output, but only the external surface of the vessel. In order to build the AT structure, we have to find also the centerline of the vessel. We reconstruct it directly from the dataset, after a first voxel data classification as vessel or non-vessel. This step can be done by voxel coding technique by Zhou [11]. Fig. 2 shows the same aortic aneurysm reconstructed with

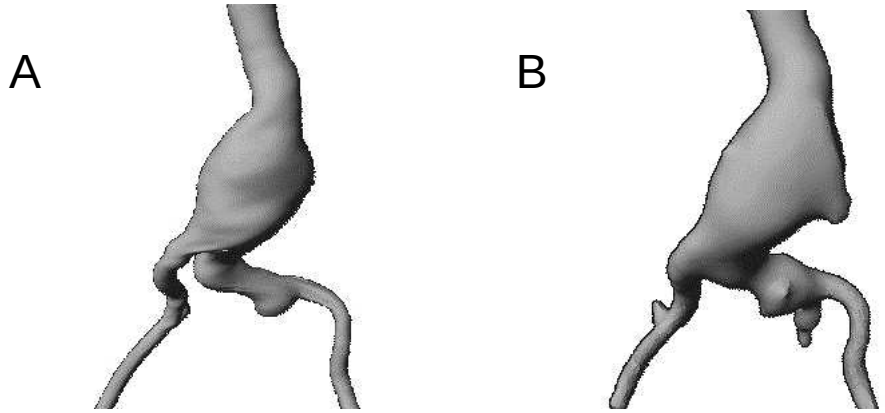

Fig. 2. The same Arterial Tree extracted from the CT data of an aortic aneurysm reconstructed with contour joining plus anastomosis (A) and simplex balloon plus centerline extraction (B).

the contours - tubes - anastomosis method (A) and the simplex - automatic centerline method (B). Results are similar, but it can be noted that the simplex reconstruction presents some irregularities where small structures not reconstructed with the contours are present. The simplex reconstruction is also more regular near the bifurcations; in general the simplex reconstruction is better with irregular vessels, but not when, for example, the presence of plaques or local structures makes convenient to correct locally the reconstruction. A method for the 3D local refinement using volume rendering and an haptic feedback device is however under development at CRS4 (see Zorcolo et al. [14]).

III. VRML97 worlds generation

VRML97 is a powerful language to describe 3D scenes, including information on point of view, shading, lights and so on and it is the standard language for Virtual Reality on the web. VRML97 plug-ins for Internet Explorer and Netscape Communicator (i.e. Cosmo Player [12]) are available on the net and can be downloaded with no charge. We tested our code with Cosmo Player 2.1 for Microsoft Windows 98/NT both with Netscape and Internet Explorer.

The conversion script

Here are some details about our data conversion. VRML worlds are generated automatically from the Arterial Tree structure. Different "nodes" of VRML97 have been used to represent the geometry of the vessel surface (IndexedFaceSet) and the vessel centerline (IndexedLineSet); The centerline is also duplicated in another part of the scene to make easier the measurement of angles and distances. The Viewpoint node is used to define a set of privileged points of view (at the end of each vessel branch and an external global view). The TouchSensor node have been used to allow user interaction with the geometries and to create buttons for the user interface. Timer nodes have been also used to create predefined animations. Routing the output of a Timer to PositionInterpolator and OrientationInterpolator nodes we control the point of view motion in order to create a driven navigation along fixed paths. Our conversion script creates automatically a guided navigation along each branch of the tree along the vessel centerline.

Measurements

The VRML97 language specification includes a particular node, called Script, that allows the introduction of code inside the file using ECMAScript or even Java. The output of the node can be used to change the value of variables in the other VRML nodes instantiated. Using ECMA scripting we implemented a method to measure parameters, with three main options. The first consists of printing the 3D coordinates and the distance from the centerline for an arbitrary point on the surface selected with the mouse. A plane perpendicular to the centerline is also shown (Fig. 3). The second consists of measuring the distance traveled by a point moving along the centerline between two user selected reference points (Fig. 4 A) . This is an extremely useful measure, since usual measurements of vessel length done with 2D imaging or endoscopy are often wrong due to the effect of vessel curvature. The last one is the measurements of angles defined selecting three points on the centerline (Fig. 4 B). With these tools the end user can perform many useful computations on realistic models that can be distributed worldwide a few hours after the image acquisition and just by using his standard web browser.

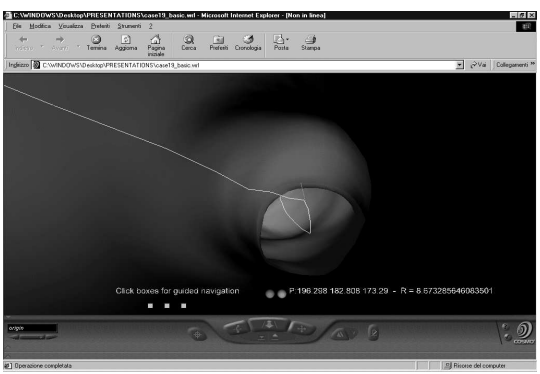

Fig. 3. The VRML2.0 model can be inspected, navigated and measured from any pc with a web browser and a plug-in. Here a "virtual endoscopy" with radius measurement is shown.

IV. Discussion

We believe that the system described here can be useful in several applications, especially considering that, even with the current prototype system running at CRS4, a geometrical reconstruction can be made available on the net a few hours after the acquisition. We are in the process of validating the system by having surgeons at different remote sites estimating the same relevant geometrical quantities on a dataset collection using either the traditional, 2D image based, techniques or the method proposed here.

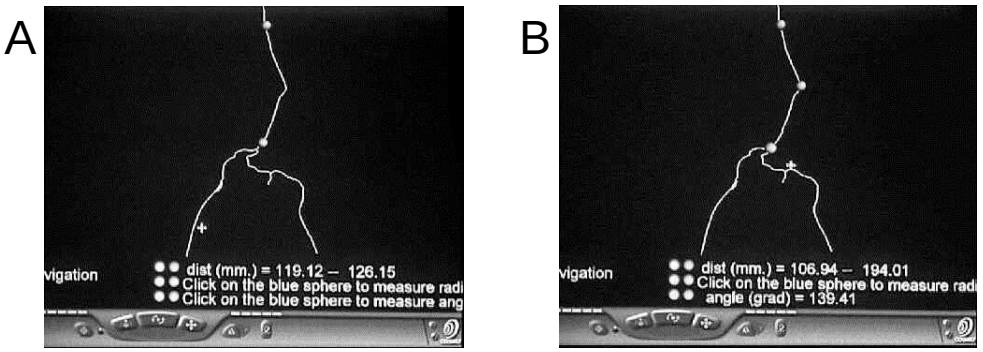

Fig. 4. A: Measurement of centerline distance: the user just clicks on two points on the centerline, and on the browser are automatically displayed the distance between the points and the distance between the points following the centerline, a very important parameter to evaluate for aneurysms. B: Measurement of centerline angles: the user can place the three reference points just by clicking with the mouse on the centerline, and the angle is automatically shown.

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