Simulation of Endoscopy

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Abstract

We have previously reported on a method to create 3D models from tomographic data. This method uses the Delaunay tetrahedrization and provides polyhedral models that are suitable for motion simulation. In this paper we explore the possibilities to use such models for a simulation of endoscopic procedures.

Introduction

Minimally invasive procedures like endoscopy and laparascopy play an increasing role in interventional treatment. Modern endoscopic devices are flexible tubes that are inserted into the interior of hollow organs. They are equipped with an optical channel that transmits an image on a video display. One typical task is to reach a tumor and make a biopsy. This implies

- *a guidance problem*: The exact position and orientation of the device is not easily determinable from the local view, especially in a branching organ.
- *a visual problem*: The tumor may be visible on CT or MRI, but not on the surface, if the wall is not infested.

Therefore it is desirable to provide a global view of the region showing the hollow organ, the exact position of the endoscope and the target (tumor). While the final goal should be to have this informations available in real time during the intervention, we propose as a first step an offline simulation on a computerized 3D model. This permits the repetition of the procedure beforehand, determining parameters like the choice of branches and the length of the trajectory.

We show in this article the simulation of a bronchoscopy.

- We calculate a 3D model of the trachea and tumor from spiral CT images,
- we define a simple physical and optical model of the bronchoscope
- and we show a method to calculate automatically the camera trajectory.

Geometric modeling

The Delaunay reconstruction can be used to obtain both a volume and a surface representation from contours distributed on parallel cross-sections [Boissonnat and Geiger, 1993]. This method is based on geometric closeness. It is a simple heuristic, similar to that of the voxel technique. However, the volume elements are not equally shaped, but consist of tetrahedra that are adapted to the object shape. The advantages of our method are as follows:

- It gets directly to a 3D polyhedral representation composed of tetrahedra.
- The property of connecting contours on adjacent planes by triangles avoids the need for anti-aliasing or interpolation steps, especially for large cross-section distances.
- Complex contours with multiple branchings, birth and death of holes and complicated splitting lines are handled correctly.
- We get a considerable data reduction compared to other volume oriented methods. Real time display of reconstructed human organs is therefore possible on standard graphic workstations. This feature may be interesting for the design of models used in virtual reality, where rendering speed is crucial.
- The tetrahedral structure can be used for applications like simulation of motion or finite element methods.

The usefulness of the tetrahedra structure has been shown in a computer simulation of childbirth [Geiger, 1992]. The simulation of an endoscopic procedure requires similar tasks: calculation of 3D objects and modeling of movements under constraints.

Physical model of the endoscope

We use a very simple model of an endoscope. The camera is represented by a cylindrical part. The viewing direction is the longitudinal axis (z-axis).

The camera has three functions:

- go forward/backward in the direction of the z-axis.

- turn around its z-axis by -180—180 deg
- pivot around the x-axis by -90—90 deg

If the camera hits the wall, we calculate the force and moment and produce then small corrective motions to reduce the forces to zero. The allowed motions are rotations around the x- and y-axis and translations orthogonal to the z-axis of the camera. Due to the geometry of the camera, it usually turns its z-axis parallel to the conduit.

Trajectory calculation

Besides the possibility to reach a target by using the above functions repeatedly, we provide also a method to calculate a trajectory automatically. The user can specify the target point interactively. We can rapidly find the tetrahedron C containing the current camera position and the tetrahedron T containing the target point. Then we search for a set of tetrahedra S connected face to face and linking C with T. We then connect C with T by a straight line segment s, and verify that it lies completely inside the trachea tetrahedra. If not, we choose M a tetrahedron from the middle of S and replace s by two segments s_1 connecting C and M and s_2 connecting M and T. This procedure is repeated recursively until all segments are inside the trachea. When the camera finally follows this trajectory, we detect an eventual penetration of the wall and modify the trajectory.

Experimental Results

We implemented this system on a Silicon Graphics workstation (Personal Iris) using the SGI graphics library gl. In one window, we show the global scene, and one window displays the camera view. Gl provides the possibility of defining a local view point and a local light source with linear light attenuation. Advanced lighting features like spotlights and square distance attenuation as well as texture mapping were not available on our workstation.

The model of the trachea was obtained from a series of 32 axial CT images (spiral CT acquisition). The ratio of in-slice resolution to slice-to-slice resolution was 1:3. In order to get a realistic impression inside the trachea it was necessary to smooth the contours and to interpolate intermediate cross-sections.

The number of triangles and tetrahedra was respectively 4500 and 19000. The time for calculating the contact between surface and camera was clearly inferior to the display time. On our antiquated SGI with an R3000 processor chip we obtained a rate of about one frame per second. Figure 1 and 2 show a typical scene.

This first model should be improved by

- mapping texture onto the walls
- using advanced lighting models
- addind gravitational forces to the camera model

An important task would be to calculate the observed surface in order to verify the complete inspection of the walls.

References

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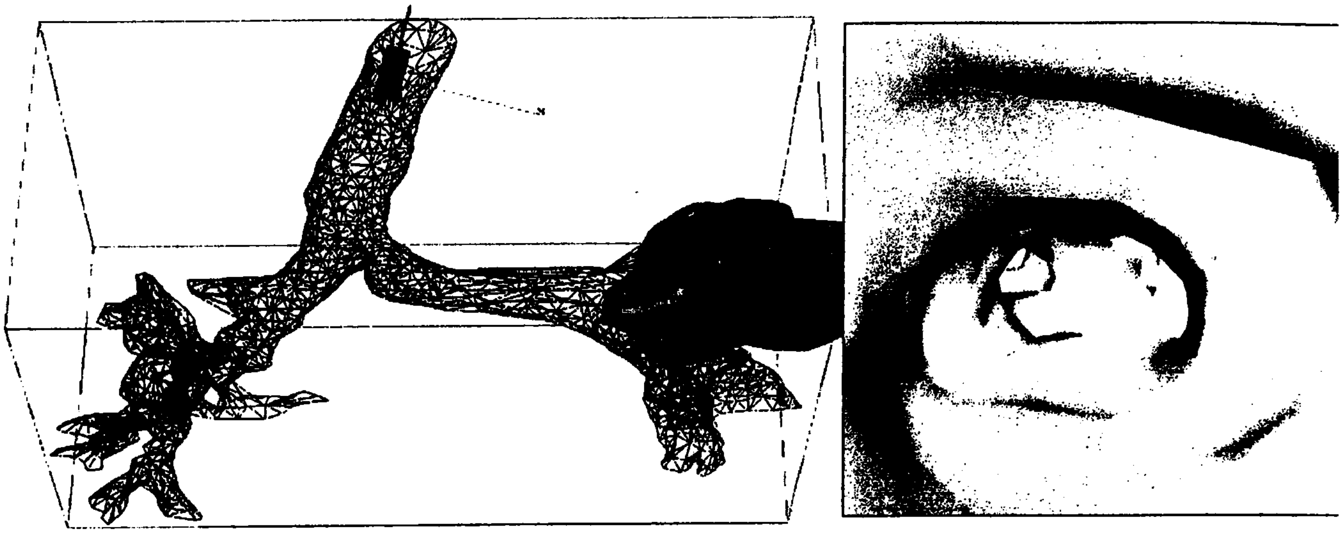

Figure 1 A view into the trachea. The global scene shows the position of the camera and a part of a tumor.

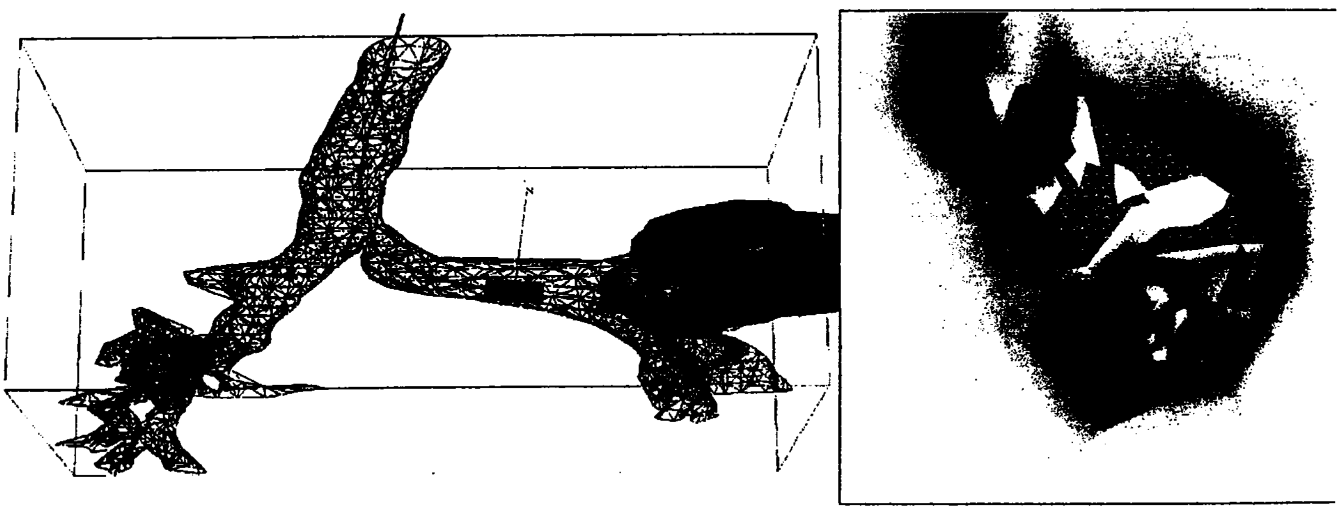

Figure 2 A view of the tumor (textured region in the local view).