Mastering Interactive Virtual Bronchioscopy on a Low–End PC

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Abstract

Virtual endoscopy presents the cross-sectional acquired 3D-data of a computer tomograph as an endoluminal view. The common approach for the visualization of a virtual endoscopy is surface rendering, yielding images close to a real endoscopy. If external structures are of interest, volume rendering techniques have to be used. These methods do not display the exact shape of the inner lumen very well. For certain applications, e.g. operation planning of a transbronchial biopsy, both, the shape of the inner lumen as well as outer structures like blood vessels and the tumor have to be delineated. In this paper a method is described, that allows a quick and easy hybrid visualization using overlays of different visualization methods like different surfaces or volume renderings with different transfer functions in real time on a low-end PC. To achieve real time frame rates, image based rendering techniques have been used.

CR Categories: I.3.3 [Computer Graphics]: Picture/Image Generation—Display Algorithms; J.3 [Life and Medical Sciences]: Medical Information Systems—;

Keywords: medical visualization, virtual endoscopy, visualization system

1 Introduction

In recent years the usage of virtual endoscopy [7] [11][12] has been extensively discussed. Virtual endoscopy allows an inner view of hollow structures by placing a virtual camera inside a three dimensional data volume most commonly produced by computer tomography (CT) or magnetic resonance tomography (MR).

The advantages of this method are clearly visible:

- since in most cases a CT or MR data set of the patient has to be acquired anyhow, no additional data acquisition has to be done. Especially the dangerous and painful endsocopic investigation can be avoided.
- Since the data set under consideration is a full three dimensional volume, not only the surface of the organ can be inspected, but also its surrounding and external structures.
- The handling and control of endoscopes is difficult, mainly due to limited flexibility.
- A real endoscope has a limited field of view.

On the other hand, the drawbacks of virtual Endoscopy are the following:

- Only densities (in case of a CT data set) or unit-less signal intensities (for a MR volume) can be investigated, therefore important color information, like bleedings, can only be seen in a real endoscopy.
- The calculation and navigation of a virtual endoscopy is very time consuming and complex, therefore it again has to be done by a specialist.
- Pathologies can be missed due to a bad choice for the parameter set, e.g., a bad threshold for the surface of a vessel can hide a stenosis.

Without doubt virtual endoscopy is the optimal tool for training and planning of a real endoscopy. The algorithm described in this paper has been developed for a planing tool of a trans-bronchial biopsy. Depending on the exact position of the bronchial tumor, a biopsy has to be taken from inside of the bronchius via the working channel of an endoscope. The current way of doing this is, that a radiologist diagnoses the original axial slices, locates the tumor and explains the position to the endoscopist using the axial slices. If the tumor itself does not dent the inner lumen of the trachea, the endoscopist has to do a blind biopsy, relying on his interpretation of the axial slices. Even for trained endoscopists it takes some time to find the correct position for the biopsy. Especially for elder patients, time plays a crucial role. Also, it is very dangerous when the endoscopist hits the aorta or the pulmonal artery. To avoid this, the biopsy has to be planned by the endoscopist using a virtual endoscopy. The demands for this are interactivity, comparability to a real endoscopy, the possibility to show the optimal position for the biopsy and to show the outer vessels that should not be hit.

2 Related Work

The common way of doing virtual endoscopy is polygon rendering of surfaces extracted by a Marching Cubes [9] algorithm. To achieve interactivity even for large scale data sets, either dedicated expensive hardware or occlusion culling [1] has to be used. Unfortunately occlusion culling is not appropriate when transparent surfaces are needed to show extra-luminal vessels. In contrast, volume rendering techniques at interactive speed always lack visual quality, general acceptability or flexibility [5] [7]. Standard acceleration techniques for volume rendering are shear-warp factorization [8], three dimensional texture mapping [2] [4] and distance leaping techniques [13].

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In many non-medical fields of visualization image based rendering techniques have been successfully used to accelerate rendering speed [10]. Using the image based rendering approach to synthesize 3D scenes has two main advantages. First, the 3D representation of the scene may be replaced with images. Second, the image synthesis time is independent of the scene complexity. Maybe a widely known application using this method is QuicktimeVR [3], which is mainly used for architectural visualization. QuicktimeVR uses 360-degree cylindrical panoramic images to compose a virtual environment. The main problem of this approach is the cylindrical panoramic projection, which does not allow arbitrary viewing angles. Actually the camera can not be turned to the top or to the bottom. This can be overcome by using cubic mapping [6].

Our approach is a combination of the idea of placing a virtual camera into an object with an environment map and the use of cubic mappings. This allows to freely turn a camera positioned at one specific point within the data volume. The algorithm will be extended by using videos for the environment maps, simulating a flight along the path of the virtual endoscopy. Adding several layers of videos, different views, like the surface of the inner lumen and the surface of the external vessels can be blended, yielding in an optimal application for the planning of a trans-bronchial biopsy.

3 System Description

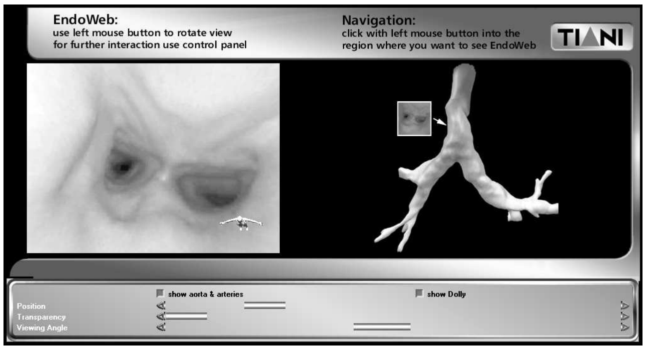

Figure 1: Screenshot of a typical working session

Figure 1 shows a screenshot of a typical working session of *EndoWeb*, a simple virtual endoscopy viewer for the planning of a trans-bronchial biopsy developed by TIANI Medgraph. The left portion of the system shows the endoscopic view generated by the described algorithm. The view can be arbitrarily rotated by just clicking with the mouse into the image and dragging it to the desired position. The endoscopist can move the virtual endoscope forwards and backwards through the trachea by moving the position slider of the user interface. Here forward and backward denotes a movement along a precalculated path. Some special positions can be chosen directly by clicking onto them on the external overview image shown on the right half of figure 1.

A second slider on the user interface determines the transparency of the surface of the trachea. If it is made transparent, outer structures like the tumor and blood vessels become visible. When the tumor is occluded by some vessels, the user can switch the display of the vessels on and off separately. Also the field of view of the virtual camera can be adapted to the users needs. All changes are reflected immediately and the virtual endoscopy can be navigated interactively.

3.1 Rendering Technique

The system takes advantage of two facts that are true for a trans-bronchial biopsy: First, the endoscopist is restricted to one special path to the tumor. Therefore no free navigation is needed, but moving the endoscope along a predefined path is sufficient for the training of the real endoscopy. Second, the operation itself is no emergency operation, therefore high precomputational costs are no problem. So the concept of the system is to display a kind of a movie that shows the surface of the trachea imitating the display of a real endoscope. The user can stop that movie and play it forward and backward at any desired speed. At every frame of the movie, the user can have a look around by rotating his virtual camera in an arbitrary direction. Whenever he wants, the user can change the transparency of the inner lumen of the trachea, thus revealing a view to the outer structure like the tumor and the vessels.

This can be achieved by rendering a cubic environment map for a cube that moves along the predefined path through the trachea. In fact, six single movies are calculated, one for each side of the cube. To simplify the user interaction, the cube is rotated while it is moved along the path, so that its main axis is always pointing in the direction of the path. This means, that the movie for the front side of the cube is identical with the view of the real endoscope. The calculation of the movies is a preprocessing step and therefore not time critical. Any volume rendering technique can be used for rendering individual frames of the movies. In our implementation a simple first hit ray-caster is used where the surface is textured with a synthetic noise texture. Due to perspective distortion, the texture facilitates the perception of the spatial arrangement. Also the head light is weakened by distance to get a more realistic simulation of a real endoscope.

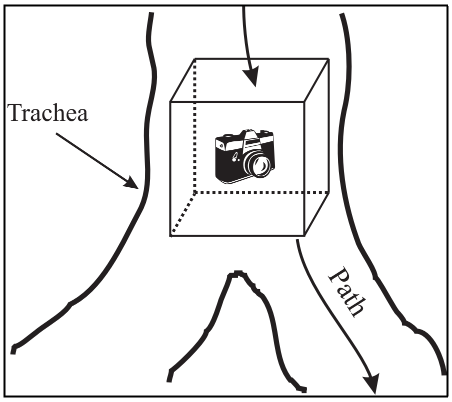

Figure 2: Camera with cubic mapping moved along a path

Figure 2 shows the virtual camera at a specific point of the path through the trachea. The camera is surrounded by a cube whose walls are textured by the cubic environment map. A rotation of the camera can be simulated by rotating the cube in the opposite direction and leaving the camera in its fixed viewing direction. Changing the field of view of the camera the cube zooms into the environment mapping texture and therefore corresponds to a zooming of the virtual endoscopy camera.

The rendering of the cube is done by simple OpenGL calls. Since only 6 textured quadrilaterals have to be drawn, the rendering speed is high even on machines with a software OpenGL emulation. Interactive frame rates are easily achieved. To achieve a better blending of the textures at the edges of the cube, the textures have a border of 3 pixels which is smoothed out by the two dimensional interpolation used by OpenGL.

3.2 Using videos for cubic mapping

To simulate the movement of the virtual endoscope through the trachea, the textures of the cube are not static images. Six video sequences are precalculated for texture mapping, one for each side of the cube. At a certain position (time step) of the cube along the path the corresponding frames of the movies are used in the texturing step. Due to high coherence video compresion is used advantageously for the video sequences. The video format is extended by parameters that encode the camera orientation for each frame, thus allowing the visualization of the patient orientation and the image resolution for each frame. This enables the radiologist to increase the image quality at important points (e.g., close to the location of the biopsy) and decrease it in regions of lower interest, like the flight between two bifurcations. This allows a much more compact data representation without reducing the image quality at regions where full resolution is required.

Within the frames of the videos additional hot-spots can be defined. These hot-spots can be used as hyperlinks, thus allowing to reference a html site with an explanation of the current frame. These hyperlinks can also be used for linking several different paths at bifurcation points. Therefore the navigation is not limited to one path, but theoretically the whole bronchius can be explored via linked paths.

3.3 Blending of Videos

As mentioned in the introduction, several different visualization methods can be used for the generation of the cubic environment mapping videos. Figure 3 shows the display of a real endoscopy in comparison to a surface shaded version and a volume rendered version of the same patient at approximately the same position in the trachea.

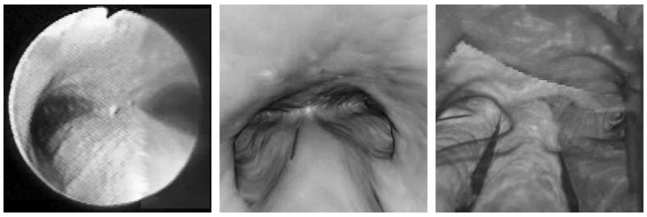

Figure 3: Real endoscopy compared with surface shading and volume rendering

As can be seen the surface shaded rendering approximates a real endoscopy very well, whereas the volume rendering shows external structures like the vessels, but does not clearly delineate the surface of the inner lumen. The transparency for the rendered surfaces can be easily achieved with the image based rendering method by stacking several videos showing different surfaces and simply blending these for the final cubic environment map. Figure 4 to 6 show three different cubic mappings for different objects at the same position. Figure 4 shows the inner lumen of the trachea, used by the endoscopist for a navigation looking close to a real endoscope. Figure 5 shows the main vessels, the aorta in red and the pulonary vessles in blue. In addition the tumor is shown in green. If some of the vessels occlude the tumor, the endoscopist can blend to the mapping shown in figure 6, where only the tumor itself is visible. With this blending functionality, the method is well suited for the planning of the biopsy.

3.4 Polygon Rendering

Since the described application relies on OpenGL (without exploiting its features too much), polygon rendering can be added in a very

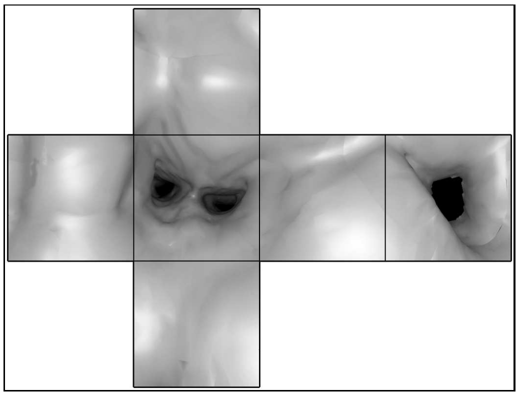

Figure 4: Cubical mapping showing the inner lumen of the trachea

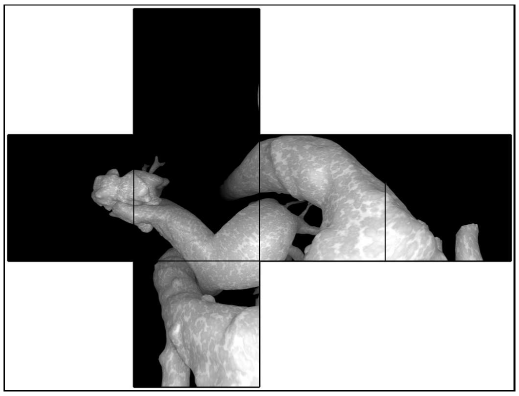

Figure 5: Cubical mapping showing the aorta (red), the pulmonary vessles (blue) and the tumor (green)

simple way. In the application this feature is used first to highlight hyperlinks (figure 1 right) by using different glyphs like arrows and second to display the position of the patient with respect to the virtual endoscope. This is done by displaying a model of a little puppet (figure 1 left). It has turned out, that this display of the virtual patient is very intuitive and quite simple to interpret. On the other hand, endoscopists do not need such a "high level" representation. The only information necessary for them is to know where the table on which the patient lies is. So the model of the puppet can be exchanged by other models, for example a simple sphere as a symbol of the patient and a plane tangent to the sphere showing the position of the table.

4 Implementation Details

The application as it is used now can be compiled as a plug in for internet viewers, such as Netscape and Microsoft Internet Explorer, or as an ActiveX Control, which allows the software to be used for example directly in text documents, and of course as a stand alone software. The communication with the software where the application is embedded in is done by an interface. Within an internet page, the plugin can for example be controlled by Javascript calls, thus allowing to adapt the user interface to the radiologists and endoscopists requirements.

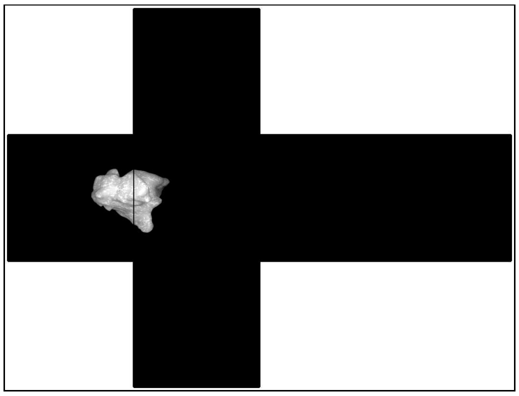

Figure 6: Cubical mapping showing the tumor

5 Conclusion / Future Work

The paper presents a simple and versatile way of viewing virtual endoscopies. The visualization methods are maid-to-measure for a planning and training application of a blind trans-bronchial endoscopic biopsy. Due to a cooperation with medical doctors in the field of bronchioscopy, the application, that has been developed and implemented by TIANI Medgraph, has been tested with several data sets of the bronchius. Here it has shown, that the proposed visualization technique allows a fast and easy navigation of the data set with a visualization close to the real endoscope, and it perfectly fulfills all requirements necessary for the planing of a blind biopsy, i.e. the detection of the optimal point for the biopsy without the risk of injuring main vessels.

The method is based on image based rendering to allow fast navigation along a predefined path within the trachea.

Appropriate frames of precalculated video sequences are texture-mapped onto the faces of a cube which contains the camera. Camera rotations, zooming are possible at interactive frame rates as only the 6 faces of a cube have to be displayed. This can be done interactivily even in a low cost PC (refer to *http://www.cg.tuwien.ac.at/research/vis/vismed/EndoWeb/* to find animations showing the performance of the system).

As a future work it is planed to couple the system with an electromagnetic tracking system. When the data set of the tomograph is then registered to the actual patient before the biopsy, the application can be used in an interoperative way, displaying the optimal way to the tumor and the optimal point for the biopsy on a second monitor side by side with the real endoscopy.

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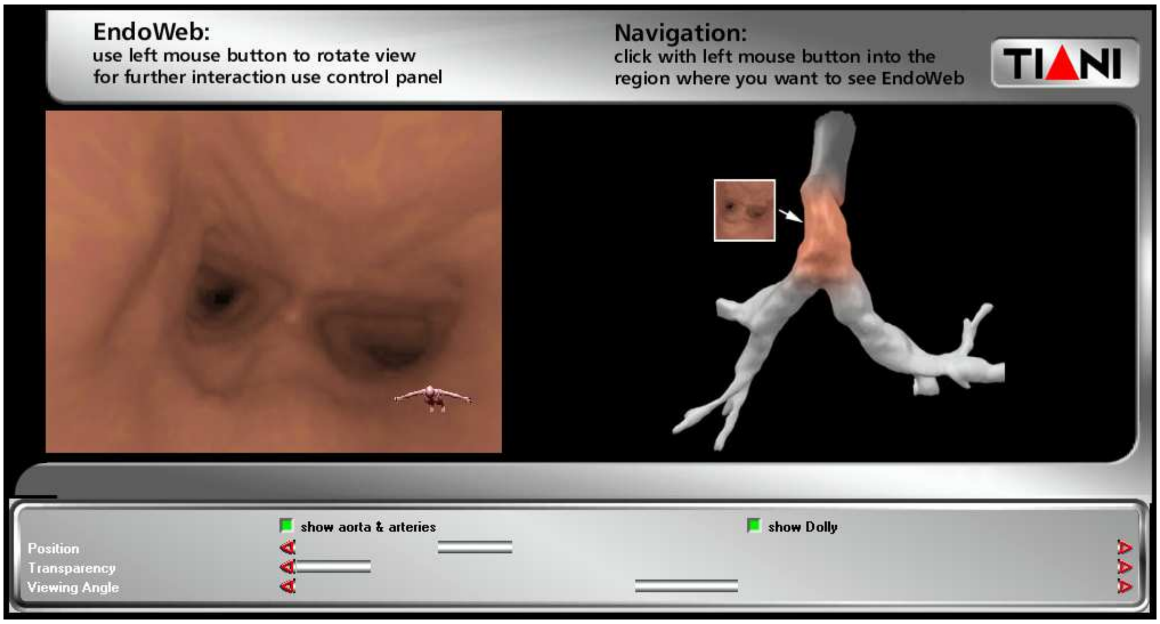

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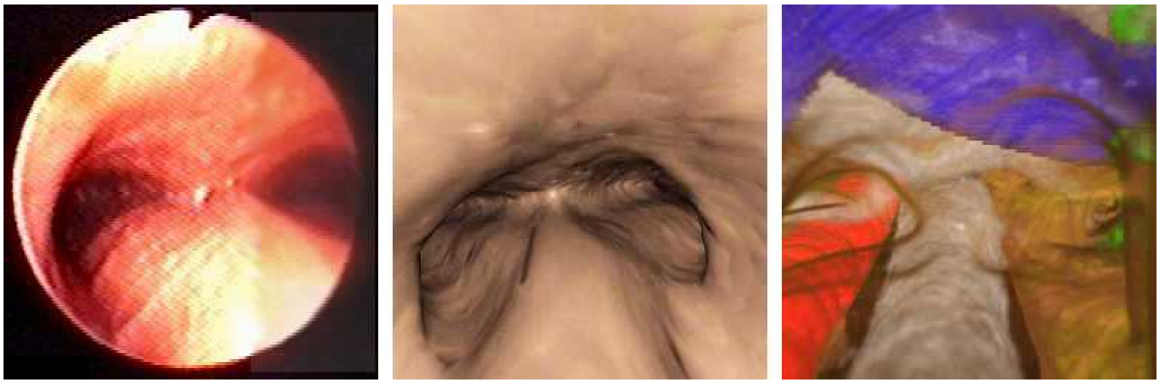

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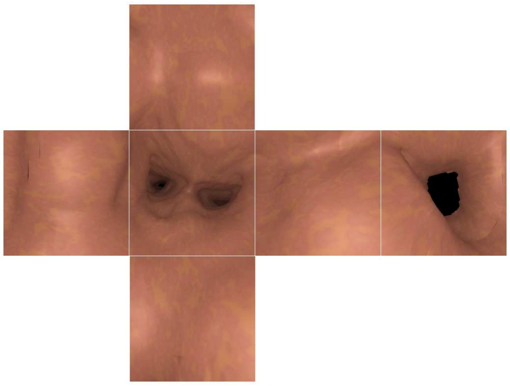
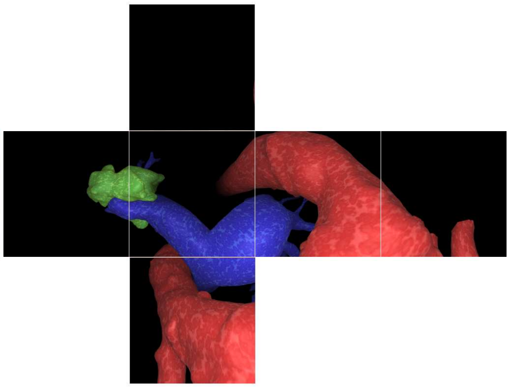


Figure 4: Cubical mapping showing the inner lumen of the trachea.



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