

Visualization of the Human Body toward the Navigation Diagnosis with the Virtualized Human Body

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Received 10 November 1997.
Revised 28 January 1998.

Abstract : In this article we present the visualization of the human body basing upon the X-ray CT and MR images. Topics and examples of images rendered by the computer are all selected from the studies in the authors' laboratory during about twenty years. Topics are classified into four groups. First we introduce a few historical pictures of cross section images, and the surface of bones and the skull. Second, the selected pictures in the surgical simulation system NUCSS (=Nagoya University Craniofacial Surgical Simulation system) we developed are shown. This system was for the simulation of the craniofacial surgery of the skull and the orthopedic surgery of the hip joint. This was the pioneering work which showed the potential of computer aid in surgery based upon 3D CT images about ten years in advance of the present rapid extension of the computer aided surgery. One of the earliest work to visualize the performance of the soft tissue - rendering of the cut skin is also included. Third, the virtualized endoscope system is presented in detail. The images of both the inside and the outside view of the bronchus, the vessel and the stomach are shown here with the introduction to the new concept of the navigation diagnosis. Finally the navigation through an Egyptian mummy is added.

Keywords : medical image processing, volume rendering, virtual endoscopy system, surgical simulation, three dimensional image processing, surface rendering.

1. Introduction

Visualization is becoming one of the most powerful tools even in the practical fields such as medicine and engineering as well as scientific research. Specific features of visualization in medicine are summarized as follows.

An object to be visualized is a human body or arbitrary parts of it.

Three dimensional data recording the whole of a real object is available.

It is closely related to the diagnosis and the treatment, which are critically important behaviors in daily life.

Let us discuss in more detail what these features mean. In medicine, particularly in diagnosis, to observe the human body in situ both in the inside and the outlook (surface) has been a strong requirement for a long time. The origin of the technology to see the inside of the human body will be the discovery of X-ray by Roentgen in 1895. Surely it was an innovation in medical diagnosis as well as in physics. The second innovation comes when computed tomography(CT) was invented in the beginning of 1970's. Thus we have got now the tools for visualizing our body by any combination of projection images and cross sectional images. Introduction of the spiral scan CT equipment to daily clinical use is also significant from the viewpoint of practical application of visualization technology. It greatly extended the applicability of CT in the ordinary diagnosis and treatment, and the possibility of visualizing the human body structure, although it was not always innovative in principle.

Other modalities of imaging have begun to be used following the X-ray CT, such as ultrasound and magnetic resonance imaging (MRI). In particular, MRI has made great progress since its appearance in the

beginning of 1980's, and is almost as important as X-ray CT now.

In this article we present the visualization of the human body based upon the X-ray CT images and MR images. Topics and examples of images rendered by computer are all selected from the studies in the authors' laboratory during about twenty years. After giving a brief explanation of basic tools : the concept of a 3D digitized picture, the surface rendering and the volume rendering, we introduce a few historical pictures of cross section images, and the surface of bones and the skull. Then the selected pictures in the surgical simulation system NUCSS we developed are shown. The system was for the simulation of the craniofacial surgery of the skull and the orthopedic surgery of the hip joint. This was the pioneering work which showed the potential of the usefulness of a 3D CT image about ten years in advance of the present rapid building up of computer aided surgery. One of the earliest work to visualize the performance of the soft tissue, rendering of the cut skin is also shown.

The third topic, the virtualized endoscope system is described in Section 5 in detail. We show here the images of the inside and the outside view of the bronchus, the vessel and the stomach with the introduction to the new concept of the navigation diagnosis. Both the surface rendering and the volume rendering are employed for visualizing the scene of the navigation inside the virtualized human body.

Finally the navigation through an Egyptian mummy is added.

2. Procedure of Visualizing the Human Body Data

Before proceeding to demonstrating practical examples, let us briefly summarize the process of the visualization of the human body data.

Input to the visualization procedure is modeled by a three dimensional (3D) digitized image, and theoretically as follows.

$$F = \{ f_{ijk} \},$$

where

f_{ijk} = density value (such as a CT value in X-ray CT images) on the i -th row, j -th column in the k -th plane.

In the case of X-ray CT images, each plane of a 3D picture corresponds to a CT slice. Often the distance between slices is larger than the pixel size in the slice in a real X-ray CT image. Therefore a suitable interpolation of a slice is performed.

There are two methods of computer graphics which have been widely used to visualize the 3D structure of the human body stored in a 3D gray tone picture. One is the surface rendering and the other is the volume rendering.

In the case of surface rendering, the surface of a target organ is extracted and represented approximately by a polygon (mostly consisting of triangular patches). This polygon is rendered with a suitable shading model such as the Gouraud shading and the gradient shading. Automated determination of the object surface (what is called "segmentation") requires higher level of image analysis techniques such as edge detection, thresholding and skeletonization in 3D space (Toriwaki, 1990). Determining borders of organs manually is inevitable in the part of abnormality like tumor, but to extract all borders of normal organs manually imposes heavy load to medical experts. Advantages of the surface rendering are high speed and easiness of execution. Most of advanced graphics machines have specific hardware built in the graphics engine to render objects represented by a polygon model with extremely high efficiency.

The volume rendering is a kind of projection of the 3D data to a 2D plane. A ray connecting each pixel on the 2D image plane with the view point is generated. All density values on the ray are accumulated and projected to the corresponding pixel on the image plane. More exactly, density values of an original CT image are transformed into suitably selected code values before the projection in order that target organs (or parts of organs) may be enhanced. This coding process is a key point for the effective use of the volume rendering. Segmentation of target organs is unnecessary in the volume rendering. This method is widely used as one of the software functions built in commercially available CT scanning systems. However the computation time is very large compared with the surface rendering. Hence it is difficult presently to use the volume rendering in the interactive mode.

3. Static and Morphological Representation

Visualization of the human body based on a CT image started more than ten years ago by showing CT values distribution on an arbitrary cutting plane, and a shaded image of an organ or bone extracted from CT images by thresholding of CT values. Figure 1 shows examples of the work in those days produced in the authors' group (Yasuda et al., 1984, 1986, 1988).

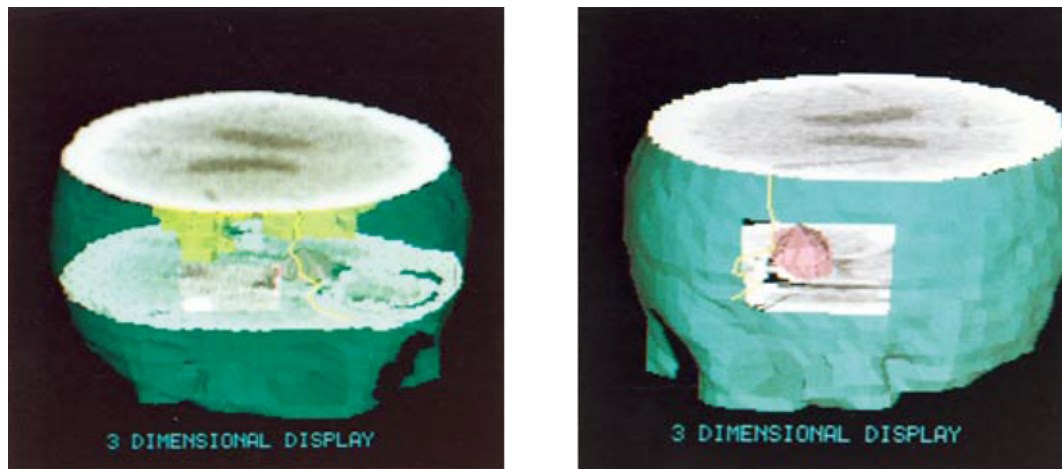


Fig. 1. Examples of visualization of the human body in early days. (Yasuda et al., 1984)

Although the image quality was very limited, such types of pictures were useful for understanding the 3D structure of the human body. Transparency effect was also used in a rendered image. However only limited numbers of slices were taken in most cases. Therefore 3D images in the present meanings were not used in these days.

In 1980's larger number of parallel slice images (100 slices with 0.2 mm interval, etc.) began to be available. Using these images we tried to develop a surgical simulation system which was called NUCSS (Nagoya University Craniofacial Surgery Simulation System) (Yasuda et al. (1990)). Here bones or skeletons were extracted automatically and modified interactively. The effect of the deformation was evaluated quantitatively. This system has been applied to more than a hundred cases both in the craniofacial surgery and the orthopedic surgery (Figs.2, 3) (Yasuda et al., 1990, 1991; Zhou et al., 1993).

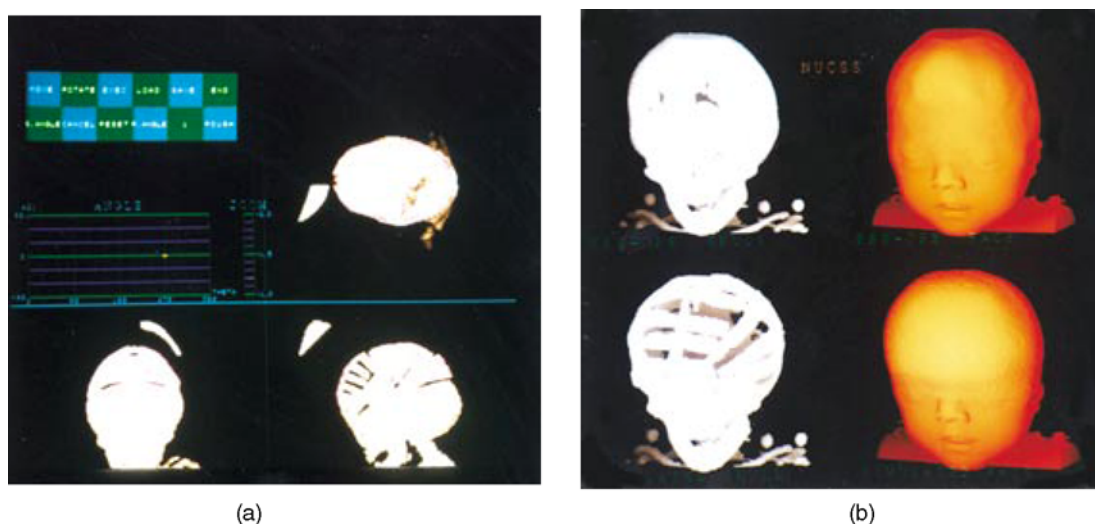


Fig. 2. Pictures generated in the surgery simulation system NUCSS (craniofacial surgery). (Yasuda et al., 1990)

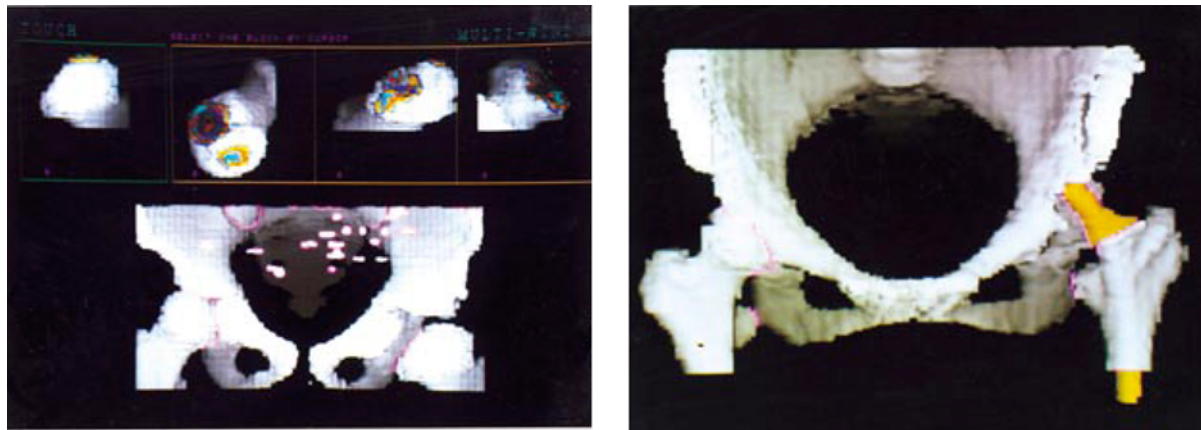


Fig. 3 Pictures generated in the surgery simulation system NUCSS (orthopedic surgery of the hip joint). (Yasuda et al., 1990; Zhou et al., 1993)

From the viewpoint of techniques for visualizing the human body, this was the first implementation of manipulating the virtualized human body, although it was not considered in such a way in those days. Only the bone was treated because it could be modeled as a rigid body. Simulation of the deformation of the skin in cutting out the head is noted as the only one experiment of simulating the performance of the soft tissue (Jin et al., 1988) (Fig.4).

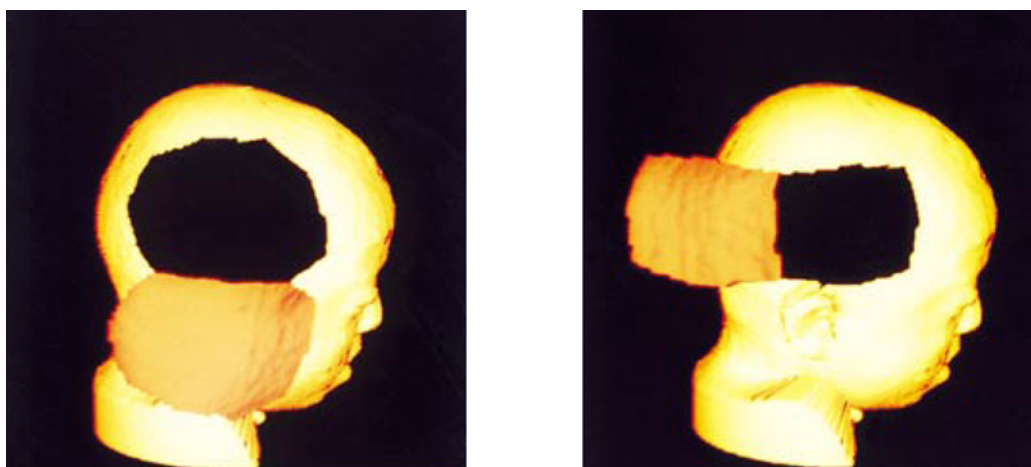


Fig. 4. Early example of rendering the deformed soft tissue (cutting of the skin). (Jin et al., 1988).

4. Virtualized Human Body

In 1990's, the spiral scan (helical scan) CT has been used widely, and began to produce large amount of 3D CT images. The slice interval can be very small compared with the past CT images : For example, 0.625×0.625 mm pixels within a slice, 1mm interval among slices, and 1mm thickness of slices are typical set of parameters for what is called a "thin slice CT image". Almost 100 slices can be taken continuously with these parameters in a short time period. Thus by interpolating slices we can obtain a 3D digitized image with almost homogeneous spatial resolution in three axes of 3D space. By storing such 3D images we can reconstruct any part of the human body on the memory of computer as a 3D virtual object. Such a reconstructed human body is virtual in the sense that it is a set of digital data in computer, but it is never an imaginary product because it exactly corresponds to a real individual human (patient) body. Considering these two features, we call this reconstructed human body data the virtualized human body (VHB).

In order to utilize the VHB, its visualization in the way suitable for individual use is indispensable. The desirable ways to visualize the virtualized human body strongly depend on its use. Let us present here examples of the visualization

collected from applications of the virtualized human body to the navigation diagnosis in the authors' laboratory.

From the view point of virtual reality (VR), the virtualized human body is considered as a kind of virtual environment. Searching or exploring the unknown (new) environment of VHB leads us to the diagnosis or examination of the corresponding patients' body. We consider this a novel type of diagnosis possible in the near future, and call it navigation diagnosis. Interactive manipulation or deformation of this virtual environment is immediately related to the simulation of the surgical treatment. The pre-operative simulation system NUCSS (Nagoya University Craniofacial Surgical Simulation System) we mentioned in the previous section is an example of this case (Yasuda et al., 1990).

5. Visualization in the Navigation Diagnosis

As the first step to realize the navigation diagnosis we have developed a family of virtualized endoscope system (VES) (Mori et al., 1995, 1996). The core of the family is the virtualized bronchoscope system (VBS) (Mori et al., 1995). By using this system we can move around quite freely inside the bronchus extracted and reconstructed from the virtualized human body. It may be considered as a simulation of the real bronchoscopy, but we can go around in any way we desire without any invasion of the real body of a patient or without worrying about physical constraints of the real bronchoscope such as the size, the elasticity and the operability.

In this system all information of the virtualized human body is obtained through images generated by the VES. Thus the design of the picture interface including visualization of the virtualized human body is of critical importance.

Let us introduce examples of rendering techniques used in VES with the examples of rendered images.

5.1 Interface

An example of the user interface used now in the virtual bronchoscope system is presented in Fig. 5. This consists of the inside view of the organ (main window - center), the outside view of the organ (subwindow - upper right), and the original CT slice image (subwindow lower right) at the cross section of the body corresponding to the observers' current position provided in the main window. By clicking the mouse button, the view point in the virtualized human body moves forward, and the inside view in the main window and the CT image in the subwindow are changed correspondingly. By generating changing views with the high frame rate (e.g. more than ten frames/sec), the user feels as if he proceeds or flies through inside the organ. In the upper right subwindow, always the whole view of the target organ is shown with a small bar indicating the position of the view point.

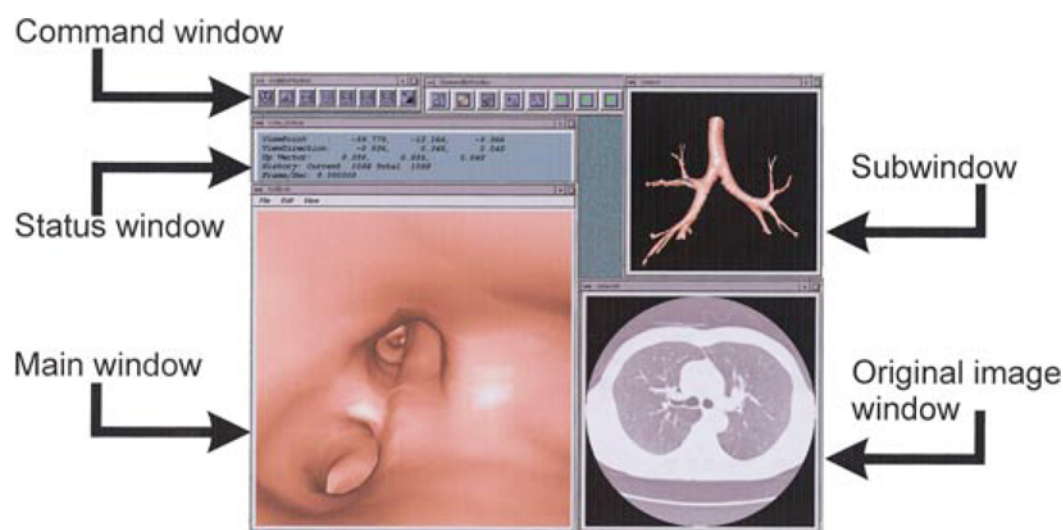


Fig. 5. Pictures selected from the virtualized endoscope system:
(1) Interface windows. (Mori et al., 1996)

5.2 Use of the Surface Rendering

The surface rendering is employed for the above interface, because the rendering speed is critical for the user to experience the virtual environment of the human body. The target organ is extracted beforehand and its border surface is approximately represented by the set of triangular patches (a polygon model). The triangular patches are determined by the Marching Cubes algorithm using both the border surface extracted automatically or semiautomatically and CT values at the voxels on the surface. Rendering is performed very fast by transferring the polygon data to the graphics engine of a computer graphics machine.

Let us present several examples. Figure 6 shows a few scenes of the navigation through the bronchus by the virtual bronchoscope system mentioned above. The same system was applied to the vessel, the stomach and the colon as well as the bronchus. Several scenes of navigation inside those organs are also presented in Figs.7 and 8.

Segmentation of the bronchus and the colon was performed automatically by the three dimensional region growing with position dependent threshold parameters and a simple thresholding with a fixed threshold value. The stomach and blood vessels were segmented interactively by a radiologist.

Typical examples of the number of polygons and the frame rate are given in Table 1. The rendering speed is closely related to the number of polygons.

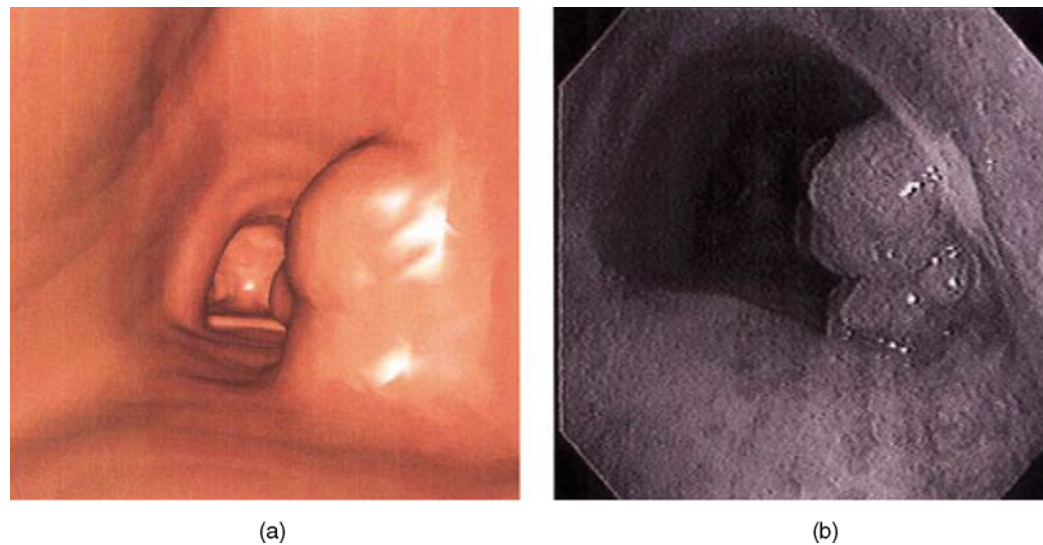


Fig. 6. Pictures selected from the virtualized endoscope system:
(2) Inside views of the bronchoscope (a) and the real endoscope image (b). (Mori et al., 1995)



Fig. 7. Pictures selected from the virtualized endoscope system:
(3) Inside views of the vessel (a) and the stomach (b). (Mori et al., 1996)

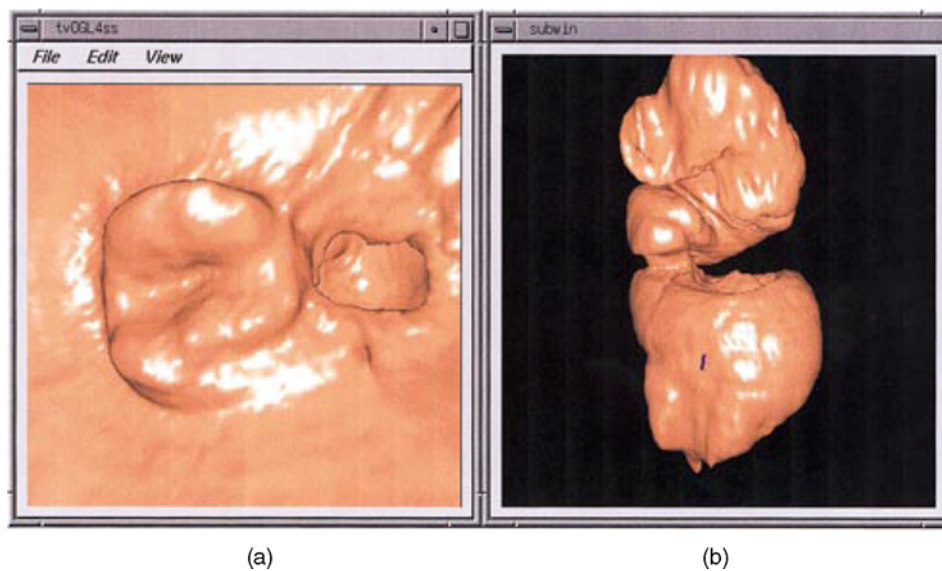


Fig. 8. Pictures selected from the virtualized endoscope system:
 (4) Inside views of the colon (a) with the outside view (b).
 (Mori 1997, Collaboration with K. Shinohara of Tokyo Metropolitan Hospital)

Table 1 Number of polygons and rendering speed - example of experimental data.

| Number of polygons | Frame rate* (frame/sec.) | Comments |
|--------------------|-----------------------------|--|
| 66305 | 6 | Bronchus Ordinary rendering |
| 66305 | 8-60 | Bronchus Fast rendering (only visible patches transferred) |
| 131662 | 3 | Colon Ordinary rendering |
| 114804 | 3 | Stomach Ordinary rendering |
| 28318 | 10 | Blood vessel Ordinary rendering |

*Computer : Silicon Graphics Inc. Indigo2 HighIMPACT
 (Specification : CPU R10000 195MHz (8.0SPECint95, 10.3SPECfp95),
 Main memory 256MB,
 1M triangle strips/sec. (lighted, Gouraud shaded, Z-buffer)

5.3 Fast Rendering

The rendering speed may not be fast enough in the case that the number of polygons are too large, e.g. 100,000 polygons or more. Acceleration of rendering is achieved (or computation time is saved) by transferring only visible patches to the graphics engine. This strategy is effective for the organ having the systematic and complicated structure such as the bronchus which has a tree structure and the colon bending in a complicated way. In our virtual bronchoscopy system we could improve the frame rate by the factor of three to ten by this method (Fig.9). Obviously the computation load to find the visible patches must be small enough compared to that of rendering (Mori et al., 1996).

5.4 Edge Rendering

In the surface rendering, we cannot see the scene of the world outside during we are navigating inside the organ. One solution of this problem is obtained by rendering only the edges of triangular patches instead of rendering the whole of the polygon surface. We call this method "edge rendering". A generated image by this method looks like a "net". Thus we "see" the scene outside the organ (usually the part of the organ in which we are navigating) through the meshes of edges. Examples are shown in Fig.10.

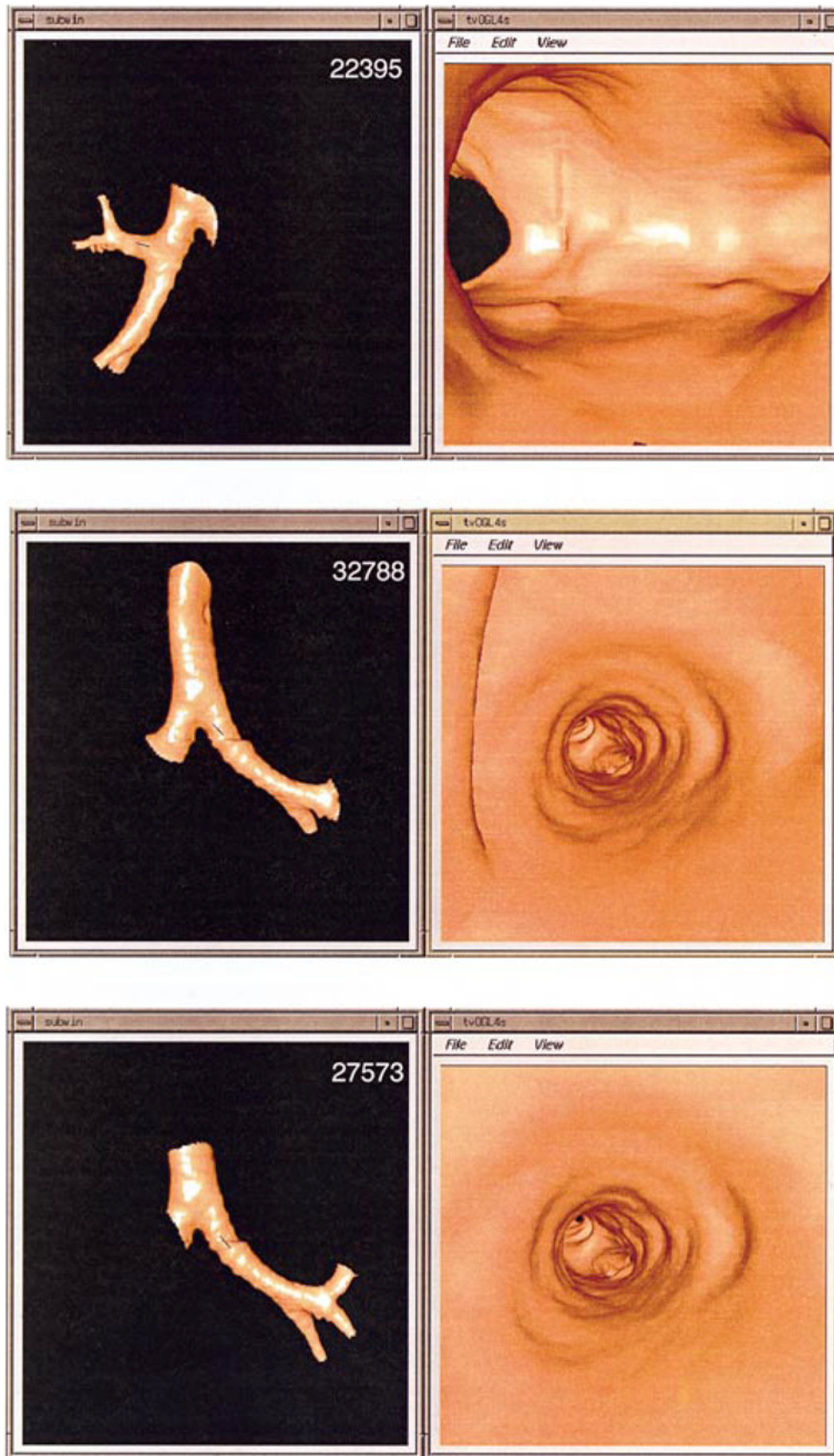


Fig. 9. Rendering only the visible parts of the bronchoscope in the virtualized bronchoscope system. (Mori et al., 1996)

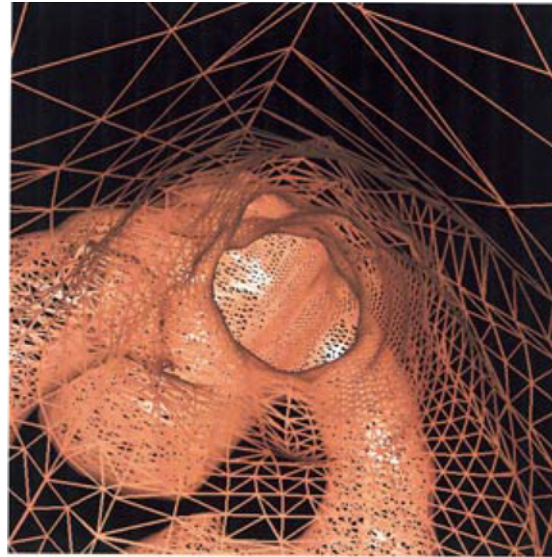


Fig.10. Edge rendering - an example seen in the virtualized bronchoscope system. (Mori et al., 1996)

5.5 Generation of the Branch Names

The medical code name is given to each branch of the bronchus in a systematic way. It is desirable for the educational use of the system to generate those names of bronchus which are seen on the screen. This was achieved automatically in our virtualized bronchoscope system by employing three dimensional pattern recognition and knowledge processing techniques. Figure 11(a) is a model of the bronchus structure (the center line of the bronchus tree) with anatomical code names attached to the corresponding branches. For a given input branch of each patient, the extracted bronchus area is thinned by a suitable 3D thinning algorithm (Saito, 1994, 1996) to be converted to a line pattern representing the center line of the patients' bronchus airway (a patient specific model of the bronchus). Next, for each of the branches which appeared on the screen, the corresponding branch in the patient specific model is detected. Then the closest branch of the general model structure is selected, and finally its name is sent to the rendering module of the VBS (Fig.11(b)). This procedure is performed automatically, but the assistance of a human expert is often needed, when the system fails in the part of the procedure mainly because of imperfect thinning.

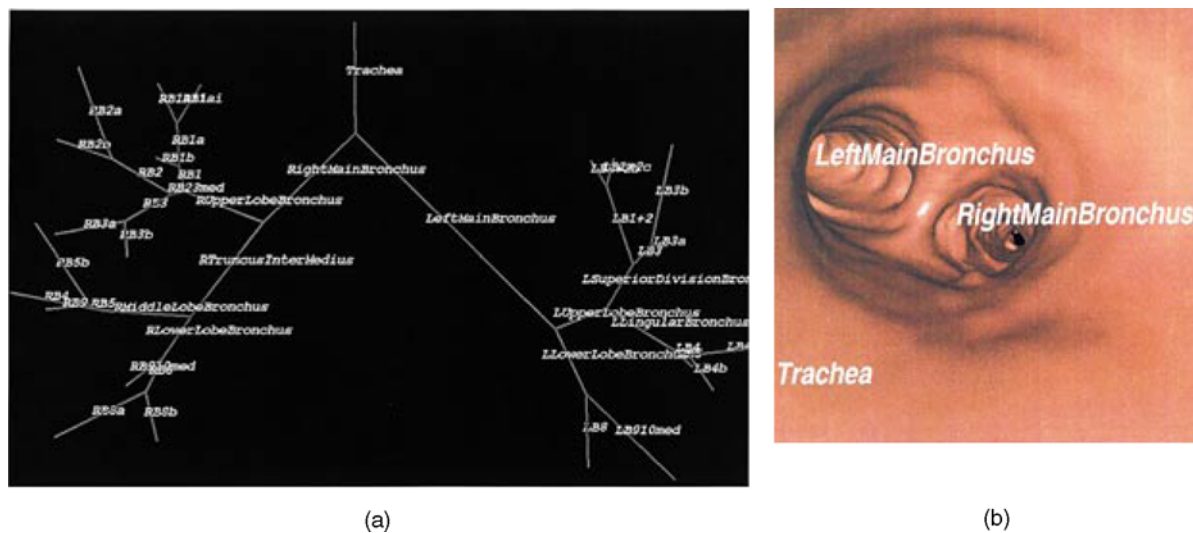


Fig.11 Generation of the branch code on the screen in the virtualized bronchoscope system (Mori et al., 1997):
 (a) Model of the bronchus with the code of each branch.
 (b) Rendered image including the code names in it.

6. Volume Rendering and Examples of Other Pictures

As was briefly referred in 2, the volume rendering requires too much computation time to be used interactively. On the other hand it has several advantages over the surface rendering. First the segmentation of a target organ is not necessary, and second it can render all of existing organs simultaneously being overlapped each other. Therefore it is suitable for rough survey before fixing the target objects for the navigation diagnosis. The disadvantages other than computation time is that it is sensitive to the selection of parameters for coloring and absorption, and that it cannot be used to manipulate a specific organ such as measuring the size of tumor and simulating surgery operations.

We are testing the volume rendering also to evaluate its effectiveness in the navigation diagnosis, presently generating a picture sequence corresponding to the navigation by off-line editing of frames. Let us show a few examples here.

6.1 Comparison of Two Methods

In Fig.12, we show the inside views of the bronchus by both the surface and the volume rendering, in which the position of the view point and the view direction are nearly the same. The edge rendering is also added for comparison. We will summarize the features of each method below:

(1) The surface rendering

The bronchus must be extracted beforehand. Once it has been segmented, the shape of the inside wall of the bronchus is clearly defined and each feature can be measured quantitatively in real time. The outside of the

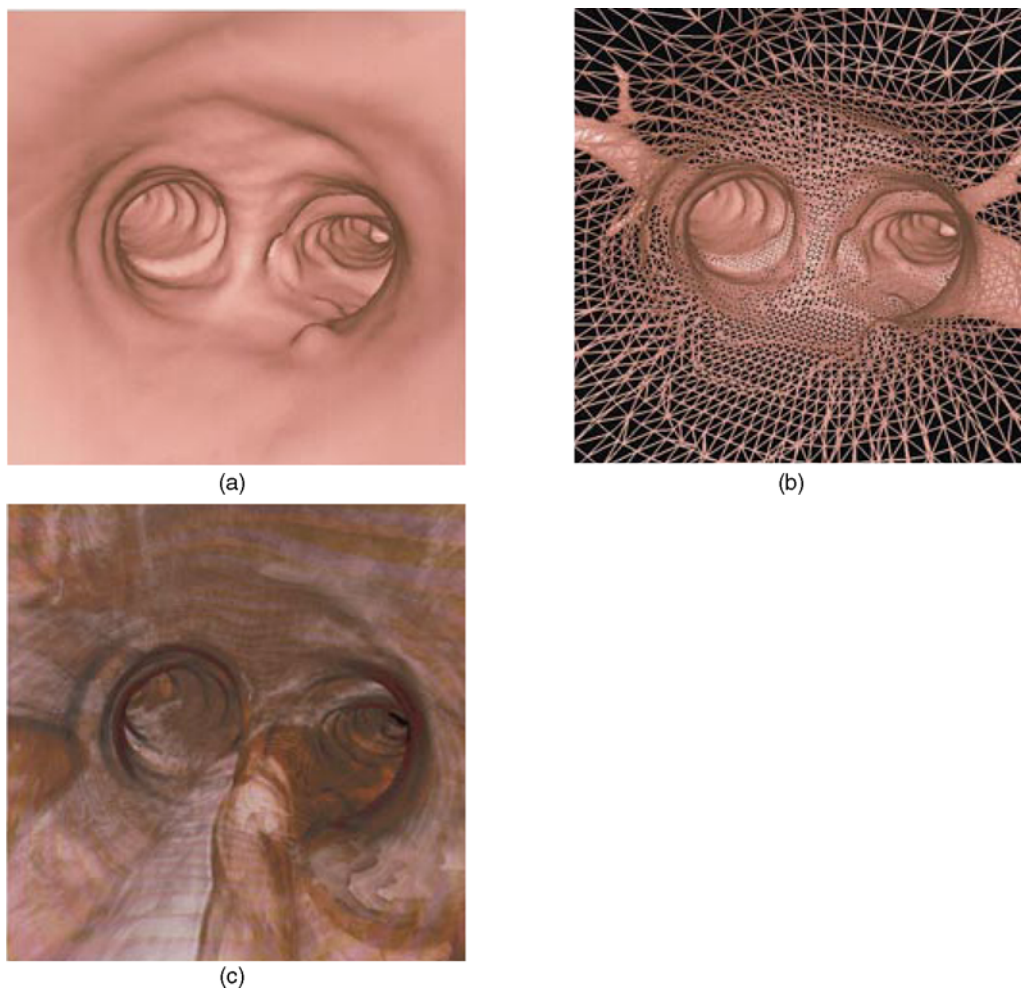


Fig.12. The surface rendering (a),the edge rendering (b), and the volume rendering (c), of the bronchus at the view point of the approximately same location.

organ cannot be seen when the view point is inside the organ.

(2) The edge rendering

The shape of the inside wall is still understandable, but the feature measurement is possible only on visible edges. The outside of the organ is seen, but only the organ segmented beforehand is rendered.

(3) The volume rendering

Various organs (including vessels, bronchus and ribs) are observed in a rendered picture existing in lung. Borders of organs are only perceived by human eye, but its location is not fixed concretely by any means. Change of the view point and the view direction in real time is hardly possible. Segmentation of the bronchus is not necessary.

6.2 Rendering the 3D Structure of Lung

To observe the 3D structure of the whole of a specific part of the body is interesting for ordinary people as well as for medical specialists. As an example, let us show the view of the left lung generated by the volume rendering in Fig.13. We can observe in them branches of vessels and bronchus, ribs, and probably the heart wall. We will be able to explore or search the lung freely with real time navigation if the rendering speed is increased in the future.



Fig.13. The 3D structure of the lung rendered by the volume rendering. (picture by Hayashi, M., Nagoya Univ.)

6.3 Revisit Mummy

To see inside an Egyptian mummy seems to be attractive, and have been tried by several researchers in different places independently (Yasuda et al., 1992; Marx, 1986; Harwood-Nash, 1979). We also took more than 700 slices of X-ray CT images of one Egyptian mummy in 1985. Resulting cross section images were processed to extract skeletons and bones by a simple thresholding. Extracted bones were displayed, manipulated and measured to test certain hypothesis. Examples of images of bones showing measurement of the size parameters are presented in Fig.14. This time we applied the volume rendering to this mummy data. The results are shown in Fig.15. Details of the internal structure remaining for more than four or five thousand years are observed clearly.



Fig. 14. Visualizing the bones around the hip joint with the measurement of size parameters after the arms shifted. (Yasuda et al., 1992)



Fig. 15. Volume rendering of mummy. (picture by Hayashi, M., Nagoya Univ.)

7. Conclusion

In this article we presented the visualization of the human body selected from the studies in the authors' laboratory during about twenty years. Introduced examples consist of a few historical pictures of cross section images, surface rendering of the skull, selected pictures in the surgical simulations system of the skull and the hip joint — pioneering work of the use of three dimensional CT images, and pictures extracted from the virtualized endoscope system — very recent research results. From the viewpoint of graphics technologies the surface and the volume rendering were employed. Advantages and disadvantages of both methods were discussed briefly. We pointed out that the methods of image analysis and recognition are also important for visualizing the human body.

Visualization of the human body (or observing the inside of living human body in situ) has been a very important and attractive problem since Leonard da Vinci's days. Roentgen made the great contribution by the discovery of X-ray. Invention of CT supported by digital computer in early 70's was the next innovation in the field of visualizing the human body.

Now the era of 3D images is beginning, being supported by the progress of helical (spiral) scan CT equipment's. Visualization is becoming more important since we cannot see the whole of such 3D images by human eyes directly. Such a 3D image is considered as a kind of virtual environment. The last group of examples concerning the virtual endoscope system is closely related to exploring and/or modifying the virtual environment. The visualization methods which can generate more realistic pictures in the interactive mode are expected to be developed in the future.

Acknowledgments

Authors thank the following people for much collaboration and valuable advice : Shigeki Yokoi, Takami Yasuda, Toyofumi Saito (Nagoya Univ.), Jun-ichi Hasegawa (Chukyo Univ.), Toyomi Fujino, MD, Hideo Nakashima, MD (Keio Univ.), Mutsuhisa Fujioka, MD (Dokkyo Univ.), Kazuhiro Katada, MD, Hirofumi Anno, MD (Fujita Health Univ.), Hiroshi Natori, Hiroshi Takabatake (Sapporo Medical College). The researches referred here were supported in part by Grant-in-Aid for Scientific Research, Ministry of Education, and the Grant-in-Aid for Cancer Research, Ministry of Health and Welfare, Japanese Government.

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