

Virtual Human Body in Medicine — Modeling, Navigation and Fusion with Real Body

Junichiro Toriwaki *

Department of Information Engineering, Graduate School of Engineering,
Nagoya University

Abstract

This article introduces briefly recent topics concerning the use of virtual human body (VHB) in medicine. Potential use of VHB as a model of the human body is first described. Then we summarize the use of VHB from two aspects: (a) search or deformation, and (b) using VHB only or both VHB and real body. As examples of each group in this classification, we present virtual endoscope, navigation diagnosis, virtual resection, augmented endoscope, and image-guided surgery.

1. Introduction

Multi detector helical CT has made great progress since 1990 and nowadays a 3D image of the human body can be utilized in ordinary diagnosis and treatment if it is necessary.

A 3D image is regarded as the virtual human body (VHB) * or virtual organ of the human body reconstructed on computer memory. It is also a kind of virtual environment build in computer. Use of VHB has the potential to realize innovative methods of diagnosis and treatment in medicine.

Potential usage of VHB is summarized in Table 1 from two aspects : (1) combination of real and virtual

* Address : 464-8603 Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan

E-mail toriwaki@nuie.nagoya-u.ac.jp

Tel. +81-52-789-3308

human body, and (2) Search or modification. The first viewpoint is the method to use VHB and real body separately or simultaneously. The second point is to observe the new virtual environment without deformation, or to modify and to deform it, if necessary.

Since VHB is a set of numerical data representing CT values or other outputs of imaging equipment, appropriate procedures to “visualize” VHB are required for doctor's eyes to perceive it. Various methods of rendering have been developed for the visualization of VHB [Bankman00, Toriwaki02b] .

2. VHB as a model

(1) Patient specific model VHB is considered as one of models of the human body. A model plays various roles in different fields such as a theoretical model of a physical phenomenon, a business model in economy, and shape models of organs. The VHB is a unique type of model in several points [Toriwaki02a]. It is very close to the original event or things it represents. The

* Note Strictly speaking, “virtual body (organ)” and “virtualized body (organ)” may be discriminated. For example, an organ generated by computer using the generic models or mathematical functions is “the virtual” organ, while the organ extracted from actual three dimensional CT images by segmentation is the organ produced by “virtualizing” the real body. In this article we use the word "virtual" for both cases.

individual VHB is a model of each individual (each patient). In this sense the VHB may be called the “patient specific model”. It may become closer to original body than any other known model, if the spatial resolution of imaging equipment is good enough. By suitable abstraction of each patient specific model we can derive the general purpose model of the body. Such general purpose model is regarded as a model of the concept of the “human body”, although it does not usually correspond to any of a real human body. Thus the VHB is used both as the model of an individual human body and as the general purpose model of the concept of the “human body”

In the future models of the human body will become available for much wider range of physical scales such as in the molecular level, the cellular level, the tissue level, the organ level, and so on [Hochne02a].

The model of VHB will also be useful as the interface to access to knowledge of the human body. This direction of extension was already presented in [Hochne95].

(2) Common use A 3D image of the actual human body or high quality of CT images are not always accessible to ordinary researchers. Furthermore the VHB including specific information is very limited. Thus a few VHB's for common use have been developed, and some of them are now being developed.

The most widely known example is the Visible Human developed in U.S.A. This is a set of CT slices covering the whole body accompanied by color photographs of actual cross sections, both taken from cadaver [visible]. Although images were different from those of living body, it contributed much to development of visualization method, picture analysis algorithms and learning of anatomy [Hochne02b]. Recently various projects are planned and promoted including MR images of the living body [Suzuki97], and the model of the body accompanying physical

properties of tissues (Sensible human project) [Takahashi00].

Three dimensional anatomical atlas consisting of 3D images was also developed using the Visible Human data, which is called Voxel Man and now is commercially available from a publishing company [Hochne02a,b]. This is a typical example of the general purpose model supported by extraordinarily realistic rendering of VHB.

3. Use of virtual human body (1)-Navigation

(1) Visualization Visualization of VHB is now performed by either surface rendering or the volume rendering in most cases. Two major points concerning visualization of VHB are (1) Use of the structural information, and (2) viewpoint position movement (Fig.1).

(2) Structural information If the object to be observed has been extracted before visualization, the surface rendering with shading can be used to render the object surface. Modeling of surfaces by mathematical functions such as Bezier curves may be applied. Polyhedron models consisting of triangular patches are also applicable. Marching cubes algorithm to generate triangular patches have been well known [Lorensen87]. Methods of segmentation are required to automatically extract the structure (detection of border surfaces, etc.) .

Unless structure has not been detected, a general rendering procedure for a set of density values filling the 3D space must be adopted. A method most widely used for this purpose is volume rendering [Drebin88, Levoy88, Mori02a, Yoshioka01]. This can be used for rendering VHB without any preprocessing. However understanding rendered images is performed by human eyes only. Manipulating a 3D object interactively through rendered images is difficult, although some possible method has been developed recently [Saito00].

(3) Viewpoint movement In rendering VHB by the volume rendering, the position of the virtual viewpoint is first selected, and "ray" is cast into virtual space from the viewpoint. A picture transformed by the perspective transformation is generated on a 2D screen of a display terminal, with a kind of cumulative summation of density values along each ray[Mori02a, Yoshioka01]. If we present images with an appropriate rate (more than ten frames/sec, for example) with systematic control of the viewpoint position, a sequence of moving pictures is obtained, which gives the feeling of "fly through" or "navigating inside the human body with a vehicle" . This leads us to the virtual endoscopy and the navigation diagnosis described in the following subsection.

(4) Virtual endoscopy By applying the above concept of "navigation" or "fly-through" to tubular organs or organs with a cavity inside, we can obtain the method to observe inside of VHB, which is known as "virtual endoscopy" or "virtual endoscope system (VES)" (Fig.2). VES was developed by Vining (1993) and K. Mori et al. (1994) independently[Vining93, Mori94,95], and now is widely known as a tool of diagnosis[Rogalla01, Suetens02].

Important factors to realize VES is as follows : (a) interactive operation of viewpoints and view directions with real time response, (b) applicability to arbitrarily given VHB, and (c) automatic segmentation of target organs. Computer graphics technique is employed for (a). Image pattern recognition and computer vision techniques are utilized for (c). Automated navigation may be used for saving doctor's load. In this case a path of navigation needs to be generated automatically. Three dimensional thinning is often utilized[Saito97]. When the shape of the organ is complicated such as colon and intestines, parts of inner wall cannot be observed on the screen of VES due to occlusion by simple one pass fly through (Fig.3). We developed the function to detect unrepresented regions so

that we may revisit and examine them from different directions[Hayashi02] (Fig.4).

(5) Navigation diagnosis The concept of free navigation is immediately extended to arbitrary parts of VHB. That is, we can observe and diagnose any part of the body at any position from any direction. This we called it "navigation diagnosis"[Toriwaki97].

A 3D picture is mathematically formulated as a function of three variables corresponding to spatial coordinate axis. Navigation is performed in this 3D space and also in the gray value space. The latter is also regarded as the continuous change of the sensitivity characteristics of the virtual eye or the virtual sensor of imaging device. This is practically realized by changing the opacity table used in the volume rendering[Toriwaki02a] (Fig.5).

4 Use of VHB (2) - Deformation

Since the VHB is a set of numerical data on computer memory, it may be deformed in any way if it is desired. Some parts of organs may be cut off when they obstruct a view of the target organ. The organ with a cavity inside may be cut and extended on a 2D plane.

Let us show examples. Applications of VES to the screening of cancer in colon have been studied since the beginning of VES, considering the advantage of avoiding the colonoscopy causing pain[Ge99] . Existence of unrepresented regions described above causes another problem of overlooking abnormal sign. One solution to this is to extend the colon wall on 2D plane, or unravelling colon wall. Thus, advantages and disadvantages of fly-through and unravelling have been discussed in several reports[Ge99]. By unraveled images we can observe the whole of the wall surface at one time without suffering from occlusion. However, the extended image is severely deformed. A VES image is similar to a real endoscope image and easy to understand, but unrepresented parts always exist.

Sometimes it is about 20 % or more of the surface of colon [Hayashi02].

Extension of the organ wall may be utilized more positively in other cases. We expanded the stomach wall onto a 2D plane, after cutting the wall along the line given interactively [Mori01]. This is regarded as a kind of virtual resection. A difficult problem here is a method of deformation. We presently adopted the spring-mass model combined with triangular patch model of the stomach surface. Again the extended surface image is severely deformed and to find the correspondence between a real endoscope image and the extended result is not so easy (Fig.6).

5 Fusion with Real Body

(1)Outline VHB is produced from a 3D image taken from each patient. Therefore VHB with appropriate spatial resolution corresponds to actual body with reasonable accuracy. This means possibility to use VHB and original real body simultaneously. This way of the use of VHB is called by various expressions such as fusion, superimposing, and augmentation. Applications include augmented endoscope, image guided intervention, etc. in addition to simple overlapping. Let us briefly introduce a few examples below.

(2)Superimposing Since VHB is close enough to real body in the physical scale, all information extracted from the VHB is always superimposed on an image of the real body of the same individual. Important issue here is the positional alignment or the registration of the real body, VHB, and doctors view parameters (position and direction). Various position sensors and algorithms for registration were developed, but details are omitted here [Hajnal01]. The first step of superimposing is to expose occluded parts of organs and tissues to observers' eyes. For instance, in the navigation* system for neurosurgery, the position and

the outline of tumor and vessels under the surface of the brain tissue are shown, being superimposed in the visual field of a microscope a surgeon is using [Maurer01]. In the case of VES, we are developing now the system to superimpose on VES images the images of organs behind wall of the tubular organ seen in an real endoscope. This might be called the augmented endoscope or fusion of the real and virtual endoscopy (Fig.7).

(3)Tracking In order to implement augmented endoscopy with real time superimposing we need to detect movement of the real endoscope camera operated by a physician. We are now trying to do this by combining different computer vision techniques, intensity-based image matching and epipolar geometry analysis. Details are presented in [Mori02b]. In this application real time camera tracking and superimposing are required almost in TV rate (30 frames /sec) (Fig.7).

Simultaneous use of VHB and real body made it possible to apply virtual reality technology to surgery and realized the image-guided surgery or image guided intervention [Suetens02, Grimson99]. An important point here is the use of intraoperative images as well as preoperative images. A surgeon to use this techniques is, as it were, given the vision by X-ray as well as the one by the ordinary vision. Here the registration among images of the same patient taken at different time and in different condition is of critical importance.

(4)Registration As was referred several times, the registration of images is an extremely important

* Note Navigation means here "to pilot and control the course or position of (a ship, aircraft, etc.)". This means in the navigation diagnosis in Section 3 (3), "to move on, over, or through (water, air, or land), esp. in a ship or aircraft". [Webster's College Dictionary, Random House, 1991]

problem common to almost all areas presented here. So many papers have been published and still far from complete solution. Examples are, multi-modal images registration (such as CT and PET; 2D and 3D, . . .), change detection (images of the same individual), image guided surgery, and use of knowledge database (use of atlas for segmentation, etc.). For details of methodology see [Hajnal01].

6 Conclusion

In this article we described briefly the use of virtual human body (VHB) in medicine from a few aspects. VHB is a 3D image of the body or organs of the individual reconstructed from CT or other data collected by imaging equipment. It has the potential to realize new methods of diagnosis and treatment. First, we described the significance of VHB as a model of the human body. Second, we introduced the use of VHB by navigation for diagnosis. The virtual endoscopy is a typical example widely known now. Third we presented the use of VHB with deformation, and fourth the simultaneous use of the real body and VHB of the same patient. They include various ways of new computer aides which are expected much in the future, such as virtual resection and image guided surgery.

The fields of computer aided diagnosis and surgery (CAD/CAS) are now progressing and expanding so rapidly. For more advanced information, we will add some references: survey articles [Duncan00, Toriwaki98,00], books [Hajnal01, Rogalla01, Bankman00, Strickland02, Suetens02, Suri02, Toriwaki02b, Caramella02], and special issues of journals [Spec98a,b,00, 01].

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References

- [Abstract02] Abstracts, International Symp. on the Virtual Human Body state of the arts and visions for medicine, Hamburg, 2002.7.1, 2002.
- [Bankman00] Bankman ed., Hndbook of Imaging, Academic Press, London, 2000.
- [Caramella02] D Caramella, C.Bartolozzi eds., 3D image processing Techniques and Clinical Applications, Springer, New York, 2002.
- [Drebin88] RA Drebin, L Carpenter, P Hanrahan, Volume rendering. Computer Graphics. Proc. ACM SIGGRAPH88, 22(3):65-74, 1988.
- [Ducan00] J Duncan, N Ayache, Medical image analysis : Progress over two decades and the challenges ahead. IEEE Trans. on Pattern Analysis and Machine Intelligence, 22, 1, pp.85-106, 2000.
- [Ge99] Y Ge, D, J Vining, D. K Ahn, and D. R Stelts : Colorectal cancer screening with virtual colonoscope. Proc. SPIE Conf. on Physiology and Function from Multidimensional Images, vol.3660, pp.94-105, 1999.
- [Grimson99] W.E.Grimson, R.Kikinis, F.A.Jolesz and P.M.Black : Image-guided surgery, Scientific American, June 1999, pp.54-61 (1999)
- [Hajnal01] J.V. Hajnal, D.L.G. Hill, and D.J. Hawkes: Medical Image Registration. CRC Press, Boca Raton, 2001.
- [Hayashi02] Y.Hayashi, K. Mori, J. Hasegawa, Y. Suenaga and J. Toriwaki: A Method for detecting undisplayed regions in virtual colonoscopy and its application to quantitation of fly-through methods, T.Dohi and R.Kikinis eds.:Proc.of MICCAI2002, pp.631-638 (2002.9)
- [Hoehne95] K.H. Hoehne, B.P. Flessner, A. Pommert, M. Schiemann, R. Schubert, and U. Tiede: A new representation of knowledge concerning human anatomy and function, Nature Medician, Vol.1, No.6, pp.506-511, 1995

- [Hoehne02a] K.H.Hoehne: Guest Editorial : Medical image computing at the Institute of Mathematics and Computer Science in medicine. University Hospital Hamburg-Eppendorf, IEEE Trans. on Medical Imaging, (In printing)
- [Hoehne02b] K.H.Hoehne : VOXEL-MAN 3D-Navigator, Springer, www.springer.de/voxel-man/
- [Levoy88] M Levoy, Display of surfaces from volume data. IEEE Computer Graphics & Applications 8(3) :29-37, 1988.
- [Lorensen87] W.E.Lorensen & H.E.Cline:Marching cubes :a high resolution 3D surface construction algorithm, Computer Graphics, 21, 4(Proc.ACM SIGGRAPH'87), pp.163-169(1987)
- [Maurer01] C.R.Maurer, Jr., F.Sauer, B.H.B.Basclé, B.Geiger, F.Wenzel, F.Recchi, T.Rohfing, C.M.Brown, R.J.Maciunas, and A.B-Hasheme : Augmented reality visualization of brain structures with stereo and kinetic depth cues : system description and initial evaluation with head phantom, Proc. of SPIE, Medical Imaging 2001: Visualization, Display, and Image-Guided Procedures, Proc. of SPIE 4319, pp.445-456 (2001)
- [Mori94]K Mori, J Hasegawa, J Toriwaki, S Yokoi, H Anno, K Katada, A method to extract pipe structured components in three dimensional medical images and simulation of bronchus endoscope images. Proc. of 3D Image Conf. 94:269-274, 1994. (In Japanese)
- [Mori95]K Mori, J Hasegawa, J Toriwaki, Y Anno, K Katada, Extraction and visualization of bronchus from 3D CT images of lung. N Ayache ed.: Computer Vision, Virtual Reality and Robotics in Medicine (Proc. First International Conference, CVRMed'95, Nice, France, April 1995), Lecture Note in Computer Science, 905:542-548, Springer
- [Mori01] K Mori, Y Hoshino, Y Suenaga, J Toriwaki, J Hasegawa, K Katada, An improved method for generating virtual stretched view of stomach based on shape deformation. CARS2001, pp.425-430, 2001.
- [Mori02a]K Mori, Y Suenaga, J Toriwaki, Fast volume rendering based on software optimisation using multimedia instructions on PC platforms, Proc. of CARS2002 : 467-472, 2002.
- [Mori02b]K.Mori, D.Deguchi, J.Sugiyama, Y.Suenaga, J.Toriwaki, C.R.Maurer, Jr., H.Takabatake, and H.Natori : A method for camera motion tracking of a bronchoscope using epipolar geometry analysis and intensity image registration of real and virtual endoscopic images, Medical Image Analysis, 6, 3, pp.321-336 (2002.10.2)
- [Rogalla01] P Rogalla, JT van Scheltinga eds., Virtual endoscopy and related 3D techniques. Springer, New York, 2001.
- [Saito95] T.Saito and J.Toriwaki : A sequential thinning algorithm for three dimensional digital pictures using the Euclidean distance transformation, Proc. 9th SCIA(Scandinavian Conf. on Image Analysis) , pp.507-516 (1995.6)
- [Saito00] T.Saito, K.Mori, Y.Suenaga, J.Toriwaki, and K.Katada: A method for specifying three dimensional interested regions on volume rendered images and its evaluation for virtual endoscopy system, Proc. of CARS 2000, pp.91-96 (2000.6)
- [Spec.98a]Special issue on Virtual and augmented reality in medicine, Proc.IEEE, Vol.86(3), 1998.
- [Spec.98b] Special issue on Computer-aided intervention, IEEE Trans. on Medical Imaging, 17,10, 1998.
- [Spec.00] Special issue on Technologies for next generation medical image processing. Trans. IEICE, Japan, J83-D-II, 2000. (In Japanese)
- [Spec.01] Special issue on computer-aided diagnosis, IEEE Trans. on Medical Imaging, 20, 12, (2001.)
- [Strickland02] R.N.Strickland :Image-processing techniques for tumor detection, Marcel Dekker, Inc., N.Y., 2002.
- [Suenens02] P Suetens, Fundamentals of Medical Imaging. Cambridge University Press, Cambridge, 2002.
- [Suri02] J.S.Suri, S.K.Setarehdan, S.Singh eds., Advanced Algorithmic Approaches to Medical Image

Segmentation. Springer, 2002.

[Suzuki97] N.Suzuki, M.Takatsu, K.Shimizu, S.Miyamoto, A.Hattori, T.Ezumi,S.Oda, T.Yanai and H.Tominaga : 3D and 4D image of human whole body structure for interactive human atlas, *Medical Imaging Technology*, 15, 4, pp.487-488 (1997.7)

[Takahashi00]T.Takahasi : What is Sensible Human Project ? *Medical Imaging Technology*, Special issue on Annual Meeting of JAMIT2000, pp.383-384 (2000)

[Toriwaki97]J.Toriwaki : Virtualized human body and navigation diagnosis, *BME (Journal of Japan Society of Medical and Biological Engineering)*, 11, 8, pp.24-35 (1997)

[Toriwaki99]J.Toriwaki and K.Mori : Recent progress in biomedical image processing — Virtualized human body and computer-aided surgery, *Trans.on Information and Systems of Japan*, E - 82D, 3, pp.611-628 (1999,3)

[Toriwaki00] J.Toriwaki : Trends and future problems in computer aided diagnosis of X-ray images, *Trans.on Information and Systems of Japan*, D-II, J83-D-II, 1, pp.3-26 (2000.1) (In Japanese)

[Toriwaki02a] J.Toriwaki : Virtual spae of the human body as a model and its exploration, *BME*, 16, 8, pp.52-59 (2002)

[Toriwaki02b] J.Toriwaki : Three Dimensional Digital Image Processing, Shokodo, Tokyo, 2002 (In Japanese)

[Vining93] D.J. Vining, A,R. Padhani, S. Wood, E.A. Zerhouni, E.K.Fishman, J.E.Kuhman : Virtual bronchoscopy: a new perspective for viewing the tracheobronchal tree. *Radiology*, Vol.189, 1993.

[Visible] The Visible Human Project, National Library of Medicine, U.S.A., [html://www.nlm.nih.gov](http://www.nlm.nih.gov)

[Wang99] G Wang, SB Dave, BP Brown, Z Zhang, EG McFarland, J Haller, MW Vannier, Colon unraveling based on electrical field - Recent progress and further work. *Proc.SPIE Conf. on Physiology and Function from Multidimensional Images*, vol.3660:125-132, 1999.

[Yoshioka01]M Yoshioka, K Mori, Y Suenaga, J Toriwaki, Fast volume rendering by software: usefulness in a virtual endoscopy system. *Medical Imaging Technology*, 190, 6, pp.477-486, 2001.

Table 1 Use of virtual human body

	Virtual human body	Real+virtual human body	Real human body
Search (observation, examination)	Navigation diagnosis Virtual endoscopy Training system	Fusion endoscopy (Augmented endoscopy)	Diagnosis
Modification	Preoperative planning Surgical simulation Virtual resection	Intra-operative aid Image-guided surgery	Surgical operation



Fig. 1 Visualization for navigating inside the virtual human body by volume rendering

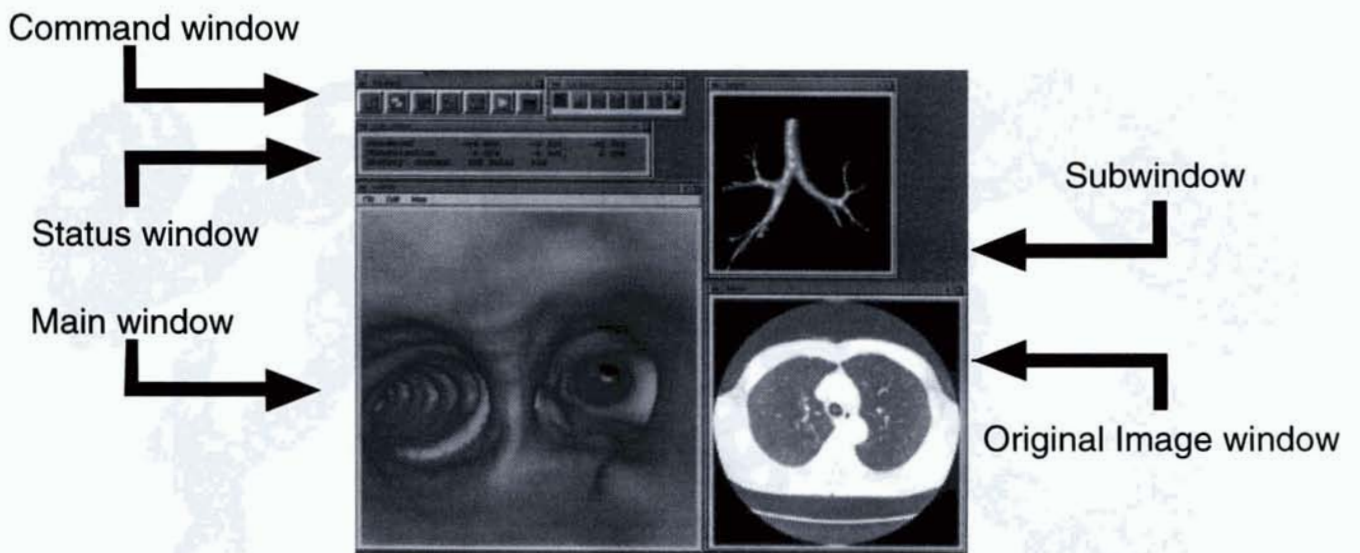


Fig. 2 A scene of the virtual endoscopy system we are now using.

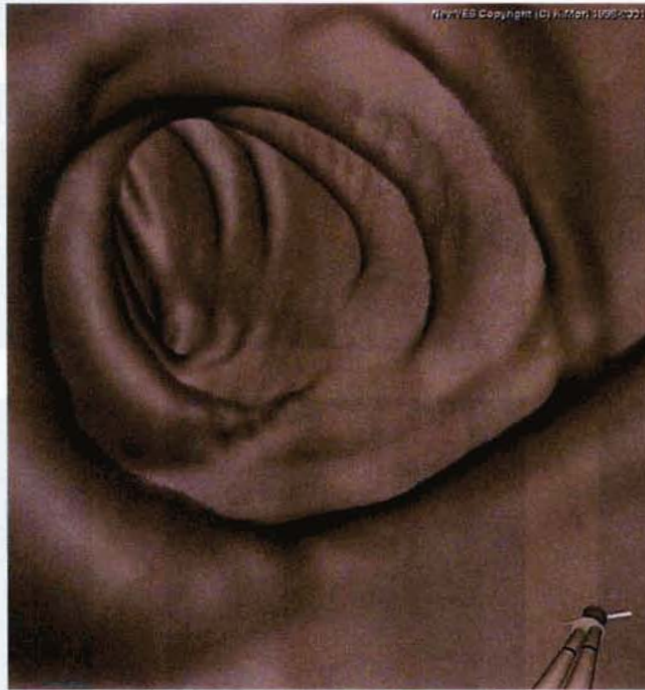


Fig. 3 A scene of the virtual colonoscopy. Occlusion occurred due to many fold patterns.

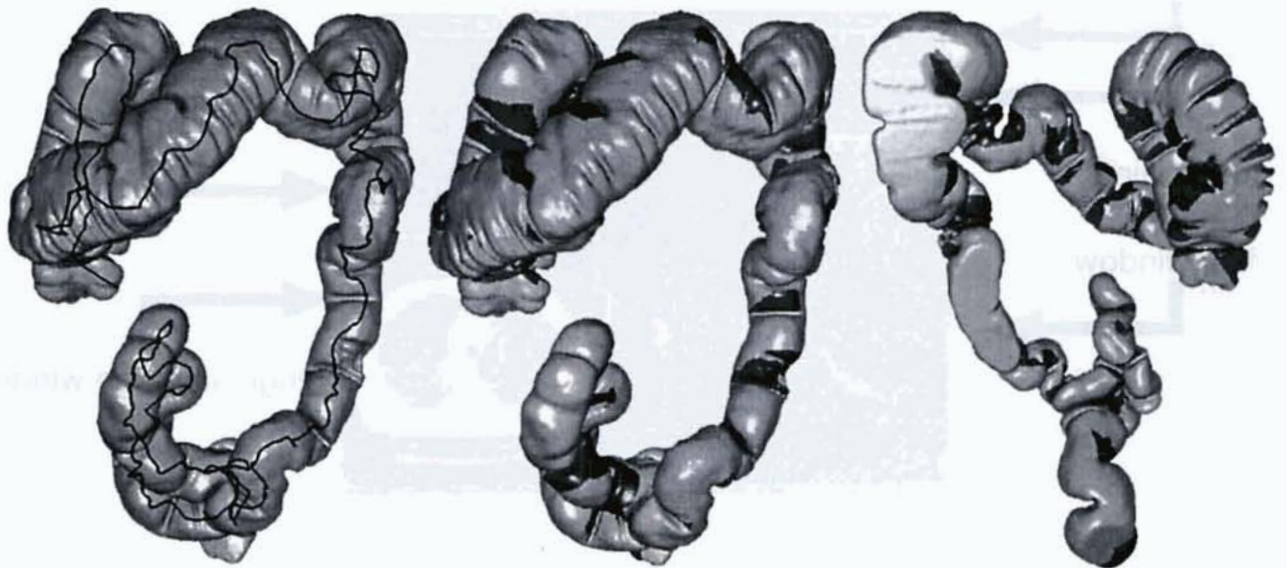


Fig. 4 Detection of unrepresented areas in the virtual colonoscopy.
Left: Path for fly through generated automatically.
Center and right : Unrepresented areas (dark parts)

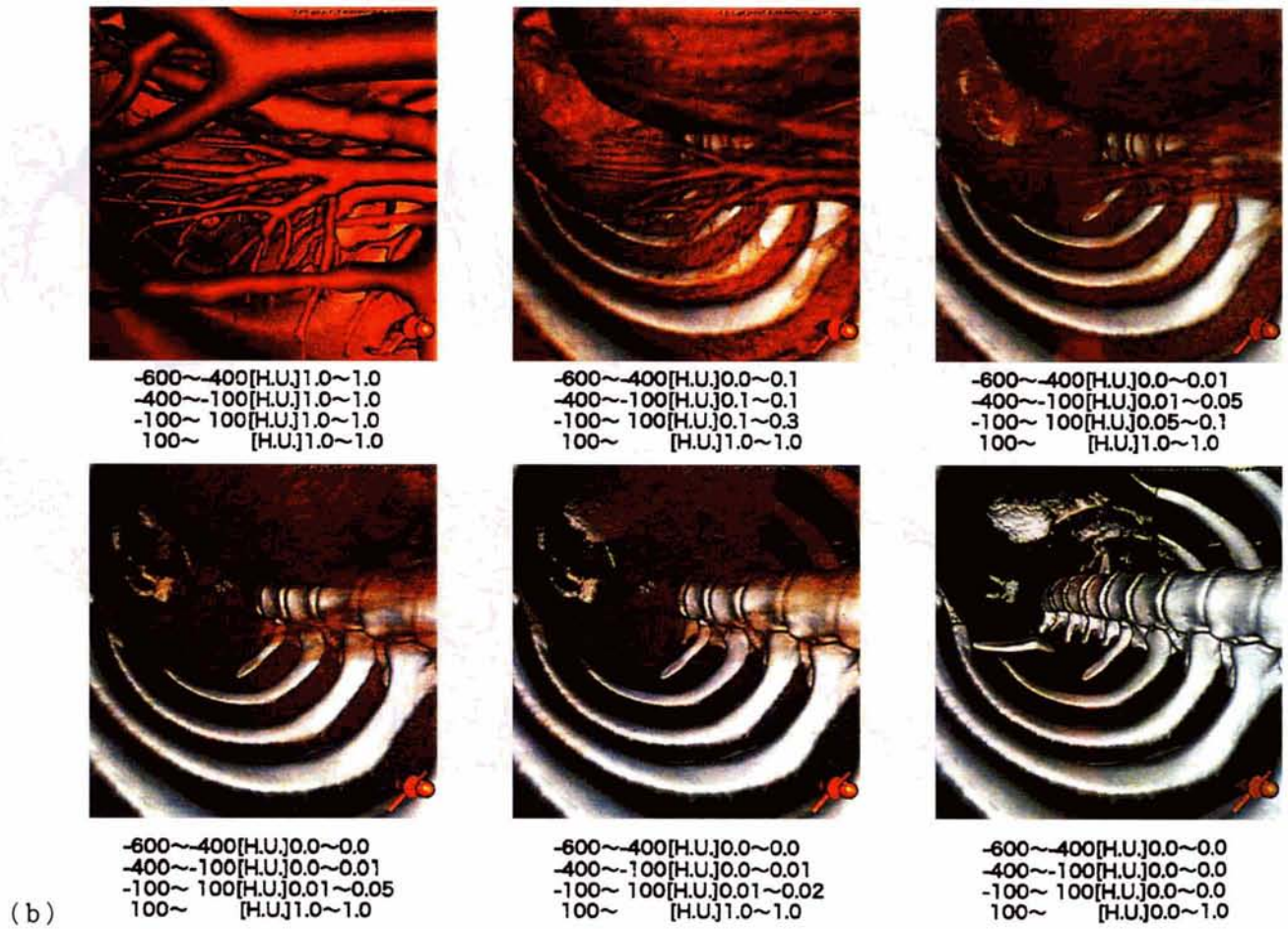


Fig. 5 Navigation in the gray value space.

Numerals show parts of the opacity table used here.

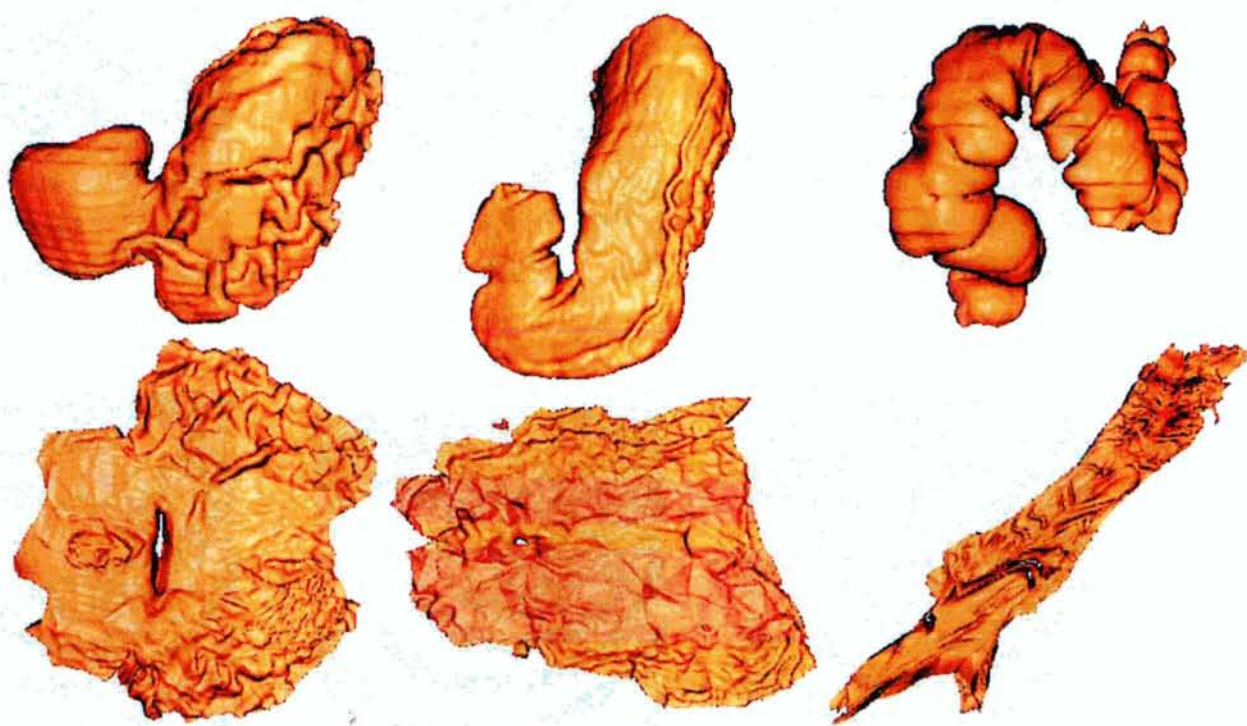


Fig. 6 Examples of unravelling (virtual resection).

Upper row : Outside views of stomach and colon

Lower row : Results of unravelling

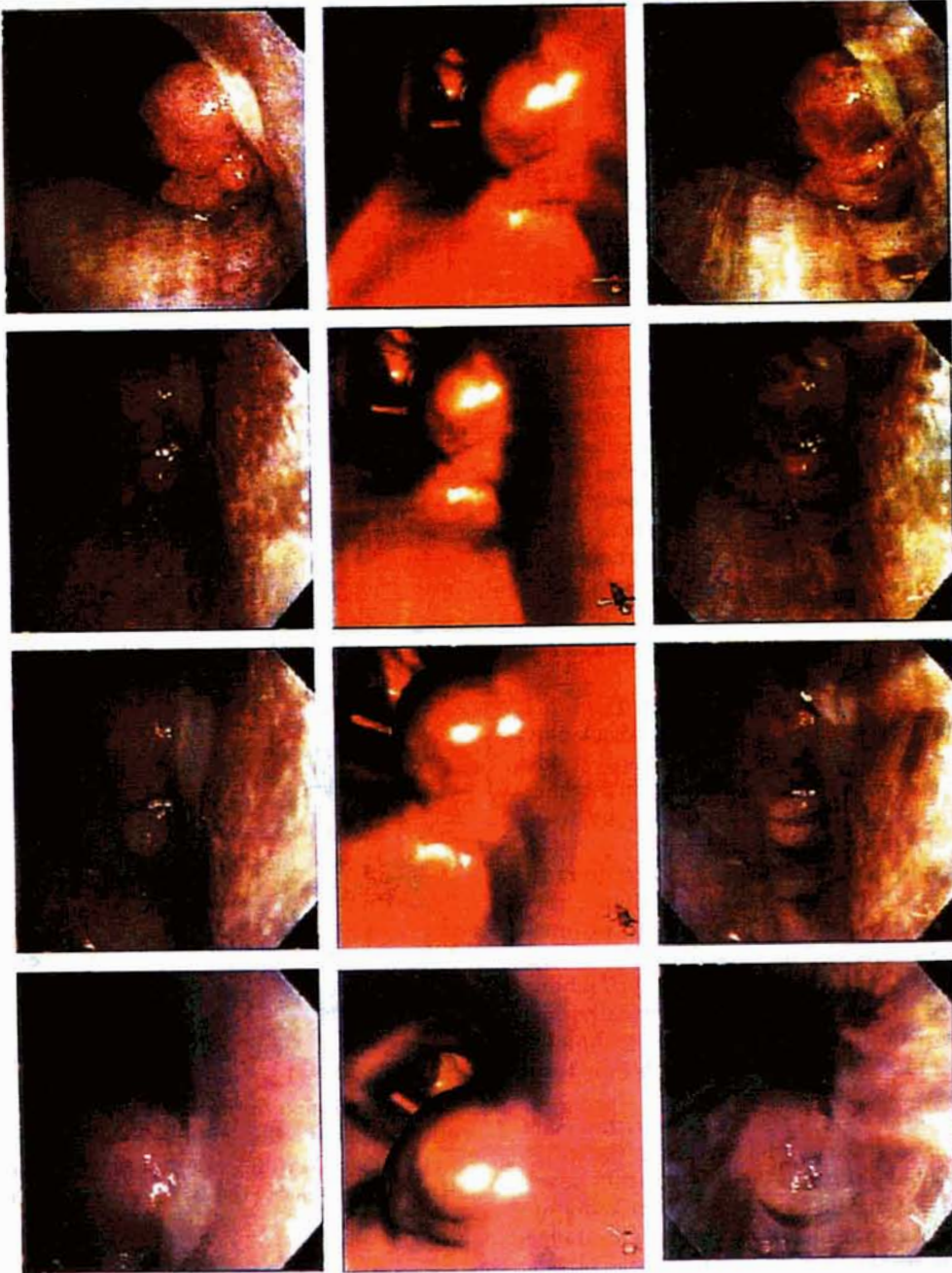


Fig. 7 Examples of tracking of endoscope camera.

Left column : real endoscope images (Trachea with tumor)

Central column : virtual endoscope images generated from tracking
and camera motion estimation

Right column : superimposing two images