Introduction to the Special Section on Virtual Endoscopy

VIRTUAL endoscopy (VE) is an integration of medical imaging and virtual reality. VE gives a computer-based alternative to standard radiological image viewing and to traditional fiberoptic endoscopy for examining the interior structures of human organs. It has evolved rapidly in the past decade, as high-resolution helical spiral computed tomography (CT) has evolved for clinical use. Unlike conventional medical visualization technology, which focuses mainly on the whole picture of a human organ with special interest in the organ's outer appearance, VE shifts attention to the inner appearance of an organ. Unlike traditional fiberoptic endoscopy, which is confined to the interior of a hollow organ, VE enables navigation between the inner and outer mucosal layers.

As compared to traditional endoscopy, which has the unique benefits of viewing the inner surface texture and removing any suspect finding during navigation, VE has many advantages, such as being less invasive, more cost-effective, free of risks and side effects (e.g., perforation and infection), and easily tolerated by the patient. VE is ideal for screening purposes and surgical planning. It has been under development in many clinical areas, such as virtual colonoscopy, virtual bronchoscopy, virtual angioscopy, virtual cystoscopy, virtual laryngoscopy, virtual myelography, and others. Technologies in VE cover almost the entire spectrum of medical imaging, from image formation to processing and visualization, as well as computer-aided detection and diagnosis (CAD) and treatment planning. Continual advancement of VE technologies will have a great impact on computer applications in medicine.

In order to promote the further development of this new technology and to accelerate it for practical use, we invited submission of research papers on VE for a special issue of IEEE TRANSACTIONS ON MEDICAL IMAGING (TMI) at the end of 2002. The invitation was posted on the TMI website and was e-mailed to both basic and clinical scientists in related fields. The invitation asked that the papers address the theoretical and technological development of VE and represent the state-of-the-art or the state-of-the-practice of work done in this area. The topics included, but were not limited to:

- image acquisition and formation strategies considering patient preparation and desired clinical information, such as means of bowel preparation/stool tagging for virtual colonoscopy, enhancement of magnetic resonance imaging (MRI) of blood vessel lumen and plaque for virtual angiography;
- correction of patient motion and image artifacts due to scanner-induced distortions, such as respiratory motion, RF inhomogeneity in MRI, and blood/urine flow;
- image segmentation, registration, fusion, and feature analysis methodologies, such as segmenting and registering features from multiple scans or multiple modalities;
- novel visualization, rendering, annotation, and navigation techniques of anatomic structures and functions;
- multidimensional CAD of abnormalities and diseases;
- clinical trials and validation of VE technologies.

A total of 22 submissions were received, covering modalities of virtual colonoscopy, virtual bronchoscopy, and virtual angioscopy, with technical focus on image segmentation, registration, dynamical modeling, flight path planning, fast volumetric rendering, interactive and active navigation, and CAD. Each submission was reviewed by at least three reviewers following the TMI normal review procedure. Eleven submissions were asked at least once for major revisions, and finally seven papers were accepted. One of these papers was published in the August 2004 issue of TMI; the other six papers are published in this special section of the November 2004 issue.

In the paper by Zalis *et al.*, an electronic colon cleansing method is presented for CT colonography (or CT-based virtual colonoscopy) which aims to relieve the stress of the conventional bowel cleansing by utilizing oral contrast to enhance the colonic materials in the CT abdominal images and image segmentation to remove electronically the enhanced materials from the colon lumen in the CT images. This research makes two significant contributions. It is expected to relieve the patient of the need for bowel cleansing and to improve patient compliance to the colon screening recommended by the American Cancer Society. It is also expected to improve the visualization on the inner mucosa of the colon wall.

Another paper on CT colonography is that by Yao *et al.*, in which image segmentation is utilized to analyze and extract characteristics of colonic polyps for CAD of polyps. Interactively navigating through the entire colon lumen (with many twisted turns and complex fold structures) to look for polyps can be time consuming. In addition, many currently available navigation methods cannot view the image density textures beneath the inner wall surface. The use of CAD can minimize the user's interpretation time and improve the detection performance by use of the internal image density textures of polyps, in addition to their outer geometric characteristics as seen during the navigation. Analyzing and extracting the inner texture and outer geometrical characteristics of the mucosal layer are expected to enhance the role of CAD in minimizing false negatives and false positives, to differentiate between malignant from benign lesions, and to improve feature-based visualization.

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The paper by Fetita *et al.* describes an important technique for VE, namely, the three-dimensional (3-D) reconstruction and visualization of the anatomical region of interest. Using high-resolution multislice CT images, the proposed method focuses on the reconstruction of the pulmonary airways. The method, which exploits the shape-analysis characteristics of mathematical morphology, is able to extract airways up to seven generations. The same concept applies to reconstruction of virtual colon and blood vessel models. In addition, the paper proposes an interesting visualization technique for viewing the airway tree transparently from the outside.

Another paper by Kiraly *et al.* describes an important tool for VE: 3-D path planning (centerline analysis). A good path helps with smooth navigation and interrogation through the entire lumen of a hollow object and is essential for follow-up live intervention. Without precomputed paths, the physician must resort to difficult manual navigation through the organ of interest. This is particularly difficult for the human airway tree, which has many branches. The work of Kiraly *et al.* discusses an application to the airway tree, but its basic principles are valid for virtual colonoscopy, virtual angiography, and other areas. A notable aspect of this paper is that it applies off-line 3-D path planning to the direct VE guidance of live human bronchoscopy.

By the name of VE, one may image a virtual reality environment that mimics the conventional fiberoptic endoscopic procedure of navigating through the inner space of a hollow object. For realization of such a virtual environment, fast and high-quality image rendering as well as smooth fly-through are necessary. The paper of Haigron *et al.* describes an active navigation method through the blood vessels for virtual angiography. Different from previous reports of planned interactive and free fly-through, this paper drives the motion of a virtual camera by visual perception during the navigation.

Another paper on visualization in virtual angiography by Wahle *et al.* presents an interactive navigation method through the blood vessels utilizing fused information from X-ray angiographic images and intravascular ultrasound data; i.e., it proposes a multimodality fusion in visualization. Visualization of integrated textures from the same or multimodality images is expected to expand the role of VE in medical imaging in particular and in medicine in general.

In order to see the benefit of VE in human studies, Cebral *et al.* utilize virtual bronchoscopy and computational fluid dynamics to investigate tracheal and central bronchial aerodynamics. In this paper, which appeared in the August 2004 issue of IEEE TMI, the authors showed how disturbances in airflow through narrowed air passages can be visualized. The use of noninvasive virtual bronchoscopy to perform physiologic modeling of airflow is expected to yield such benefits as prediction of the need for intervention before narrowing becomes symptomatic, documentation of successful treatment, and prediction of transport of inhaled pharmaceutical aerosols for treatment of other systemic illnesses.

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