

# Interactive Electronic Biopsy for 3D Virtual Colonoscopy

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## ABSTRACT

We propose an interactive electronic biopsy technique for more accurate colon cancer diagnoses by using advanced volume rendering technologies in computer graphics. The volume rendering technique defines a transfer function to map different ranges of sample values of the original volume data to different colors and opacities, so that the interior structure of the polyps can be clearly recognized by human eyes. Specifically, we provide a user-friendly interface for physicians to modify various parameters in the transfer function, so that the physician can interactively change the transfer function to observe the interior structures inside the abnormalities. Furthermore, to speed up the volume rendering procedure, we propose an efficient space-leaping technique by observing that the camera parameters are often fixed when the physician modifies the transfer function. In addition, we provide an important tool to display the original 2D CT image at the current 3D camera position, so that the physician is able to double check the interior structure of a polyp with the density variation in the corresponding CT image for confirmation. Compared with the traditional biopsy in the procedure of optical colonoscopy, our method is more flexible, noninvasive, and therefore without risk.

Keywords: Virtual colonoscopy, virtual endoscopy, direct volume rendering, transfer function, 3D medical imaging, scientific visualization, interactive navigation, cancer diagnosis, electronic biopsy, virtual reality.

## 1. INTRODUCTION

Colorectal carcinoma is the third most commonly diagnosed cancer and the second leading cause of death from cancer in the United States. Often it is diagnosed at an advanced stage, after the patient has developed symptoms, explaining its high mortality rate. Since most cancers arise from polyps over a 5 to 15 year period of malignant transformation, screening programs to detect small polyps less than 1 cm in diameter have been advocated. Optical colonoscopy is the commonly used accurate diagnostic procedure. Unfortunately most people do not follow this procedure because of the associated risk, discomfort, and high cost. In order to dramatically increase the number of people willing to participate in screening programs, we have been making efforts towards a computer-based screening modality, called 3D virtual colonoscopy [1,2], as an alternative to optical colonoscopy, by employing advanced computer graphics and visualization techniques. In order to further improve the diagnostic accuracy of our virtual colonoscopy system, we propose *electronic biopsy*, an on-line interactive diagnosis tool, which helps the physician to determine different kinds of colonic abnormalities and to distinguish them from leftover stool.

The virtual colonoscopy system takes a spiral CT scan of the patient's abdomen after the entire colon is fully cleansed and distended with air or CO<sub>2</sub>. Several hundred high-resolution CT images are rapidly acquired during a single breath hold of about 30-40 seconds, forming a volumetric abdomen data set. A model of the real colon is then segmented from the abdomen

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data set [3]. Colon centerlines and other important information are further extracted in a preprocessing stage [4,5]. The virtual colon can then be viewed either by automatic planned navigation following the center-line of the lumen of the colon, providing a general overview of the inner colonic surface [1], or by interactive navigation for a more detailed study of suspicious regions [2]. In our previous work, we developed this virtual colonoscopy system on a high end 16-processor SGI Power Challenger [6] and successfully ported it onto low cost PCs (Personal Computers) [7] with the world's first commercial real-time volume rendering accelerator, called *VolumePro*, which was produced by Mitsubishi Electric Research Laboratory [8] based on the Cube-4 architecture developed at SUNY Stony Brook [9]. We have already confirmed that we can visualize polyps as small as 3 mm, and polyps that have been detected in optical colonoscopy have also been identified with our virtual colonoscopy. Our work in this paper is to enable our system to distinguish various types of polyps and to differentiate polyps from the residual stool, so as to enhance its accuracy when detecting potentially cancerous growths in the colon.

We propose an interactive electronic biopsy technique for more accurate colon cancer diagnoses by using direct volume rendering technologies in computer graphics, to augment either conventional surface-rendering-based or volume-rendering-based virtual colonoscopy procedure. The volume rendering technique defines a transfer function to map different ranges of sample values of the original volume data to different colors and opacities, so that the interior structure of the polyps can be clearly recognized by human eyes. Our contribution in this paper includes several aspects. First, we provide a user-friendly interface in section 2, for physicians to conveniently modify various parameters in the transfer function. Second, we implement a fast volume rendering in section 3, by exploiting an efficient space-leaping technique during the observation of the interior structure of polyps with different transfer functions. Third, we develop an important screening tool in section 4, to confirm the discovery from our electronic biopsy with the original CT information from the patient data set. The experimental results are reported in section 5.

## 2. USER INTERFACE FOR TRANSFER FUNCTION

We employ volumetric ray casting algorithm [10], an accurate volume rendering technique, to generate virtual endoscopy views inside the colon, because we strongly believe that image fidelity is paramount in medical applications. Two different visual effects are normally required during the interactive navigation in the colon. One is the mostly opaque view during navigation, called a *navigation view*, as shown in fig. 1 and 2a; the other is the translucent view during our electronic biopsy, to display the interior structure of polyps beyond the colon wall, called a *biopsy view*, as shown in fig 2b. Our ray-casting algorithm is capable of generating these different views by using different *transfer functions* during rendering.

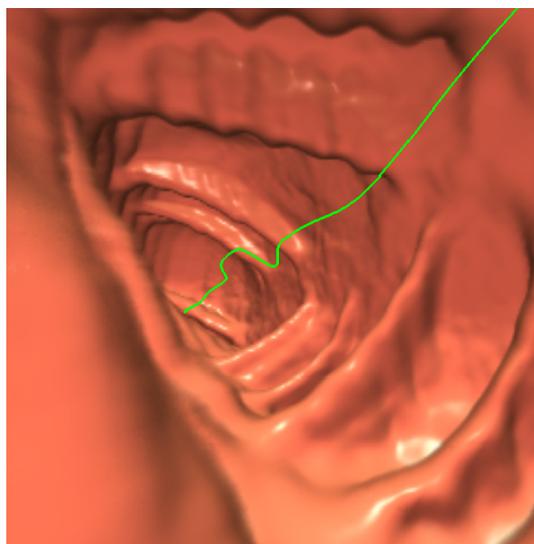


Figure 1. A photo-realistic navigation view in the human colon.  
(The green line is the colon centerline that guides the navigation)



(a) opaque navigation view (b) translucent biopsy view (c) reconstructed CT image  
 Figure 2. A close view of a 4mm polyp detected by using the electronic biopsy.

A transfer function maps certain ranges of voxel values of the original volume data to different colors and opacities. It is often implemented as a lookup table of 256 quantities indexed by voxel values. Each of the red, green, and blue material color components has a maximum value of 255 and a minimum of zero. Opacities range from 0.0 to 1.0, with 1.0 being fully opaque and 0.0 fully transparent. By changing the opacities and colors in the lookup table, we are able to generate various views as illustrated in fig. 1 and 2 with different level of transparency. This capability is extremely critical during the electronic biopsy where the physician needs to adjust the transfer function to obtain a clear translucent view of the interior structure of the polyp beyond its boundary. However, the normally hard-coded implementation of a specific transfer function in the rendering algorithm prohibits this capability. One solution widely adopted is to predefine several different transfer functions, and let the user select one from them during rendering. Obviously, the user has a very limited flexibility.

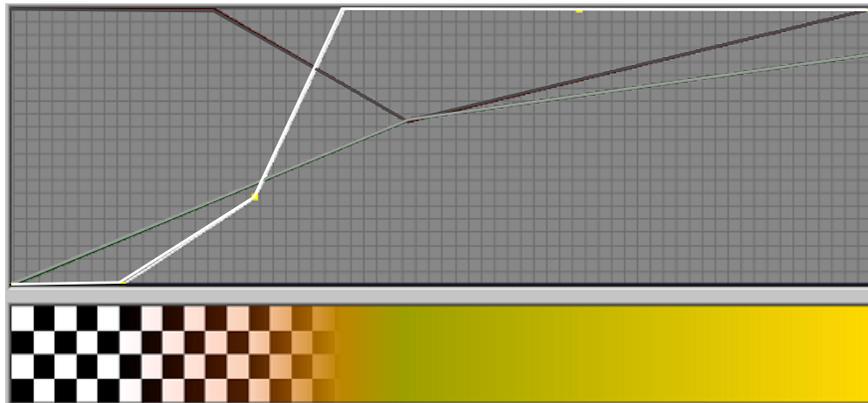


Figure 3. Interactive user interface to change transfer function during rendering.

We implement a more flexible graphics user interface for the physician to interactively change the transfer function during the navigation, as shown in fig 3. There are two panels in this interface. The upper one displays a graph of the four curves that map each voxel value to certain red, green, blue and opacity values, respectively. The horizontal axis of the graph is voxel values ranging from zero to 255; the vertical axis is the corresponding colors and opacities. The physician can use the mouse to specify or change a transfer function by activating one of the four curves and dragging it to produce a desired viewing effect, which is immediately displayed in the lower panel in fig. 3. Therefore, when a suspicious abnormality is found during navigation, the physician can interactively change the transfer function to observe the interior structures of abnormalities beyond the colon wall. For example, the physician may decrease the opacity of the voxel values corresponding to the colon surface, so that the materials beyond that surface become visible. The physician may also want to increase opacity of the voxel values corresponding to the materials inside the polyps and assign brighter colors to highlight them. In order to free the user from the labor of establishing a transfer function from scratch, we provides library of typical transfer functions for normal use, yet the user make a change at any time through the user interface and save the change for later use.

### 3. FAST VOLUME RENDERING FOR POLYPS

Although ray-casting algorithm is capable of producing high quality images during navigation (as shown in fig. 1), it was originally a time-consuming technique due to the large number of samplings along all the rays [10]. Therefore, many efforts have been made to speedup ray casting rates in the last decade, among which rapid skipping over empty space during ray sampling becomes an effective optimization toward real-time rendering rates without trading image quality for speed [11,12]. In this paper, we implement a simple but efficient space-leaping algorithm as illustrated in fig. 4, by observing that the camera parameters are often fixed when the physician modifies the transfer function to visualize the interior structure of polyps during the electronic biopsy procedure.

Specifically, assume that the physician finds an abnormal area during navigation and stops at the camera position for a more detailed observation. In order to look through the opaque colon wall and observe the interior structure of the polyp, the physician uses our graphics user interface to map the voxel values around the colon wall to lower opacity values and highlight the voxels beyond the colon wall at the same time. Once such a new transfer function is specified, our system updates the image immediately by ray casting. As long as the camera location and orientation do not change, we can rapidly skip over the empty ray segment between the camera position and the colon wall along each ray and only conduct ray sampling beyond the colon wall. The jumping distance between the camera and point  $P$  on the colon wall (see fig. 4) has already been detected during the previous rendering of the mostly opaque colon wall in our regular navigation mode. Since the polyp interior is always farther away than the colon wall from the eye, we can safely jump to the colon wall without losing any useful information.

The only cost of our space-leaping optimization is to store the first intersection between each ray and the colon surface into a depth buffer. Used in our electronic biopsy, this optimization is provably more effective than the potential-field-assisted ray casting proposed in [6] that requires multiple jumps before approaching the colon wall. It is also superior to the surface-rendering-assisted ray casting proposed in [13] where one-step jumping over the empty space is based on a Z-buffer established by specific graphics hardware during an extra surface rendering.

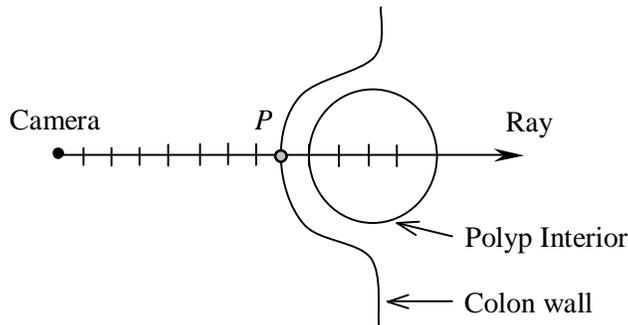


Figure 4. Accelerating ray casting by space leaping in the colon.

### 4. SCREENING TOOL FOR CONFIRMATION

To meet the clinic requirement, we further developed an important 2D screening tool for the physician to confirm the discovery with the original CT information from the patient data set once a polyp is detected by using our 3D electronic biopsy. Specifically, this tool displays a magnified gray-level CT image at the current image plane (see fig. 2c), so that the physician is able to double check the interior structure of a polyp with the density variation in the corresponding CT image for confirmation.

We minimized the programming cost for this tool by implementing it as a *degenerated* ray casting, where each ray is sampled only once at each image pixel by trilinearly interpolating the voxel value from those of its eight neighboring voxels in the original CT volume. As a result, we obtain high quality CT images perpendicular to the camera orientation at a very short time by reducing the ray casting complexity from  $O(N^3)$  to  $O(N^2)$ . To further increase the functionalities of this screening tool, we implement two sliders to change the *depth* and the *field of view* of the image, respectively. By using the depth slider, the physician can move the image back and forth along the camera orientation to obtain a continuous sequence of 2D cross-

sections of a polyp (see fig. 5a); with the field-of-view slider, the physician can enlarge or shrink the visible area on the image plane to obtain a global overview of the polyp with its surroundings or make a more detailed look of the cross-section of the polyp (see fig. 5b). These two functionalities are proven to be very helpful to clinic diagnoses.

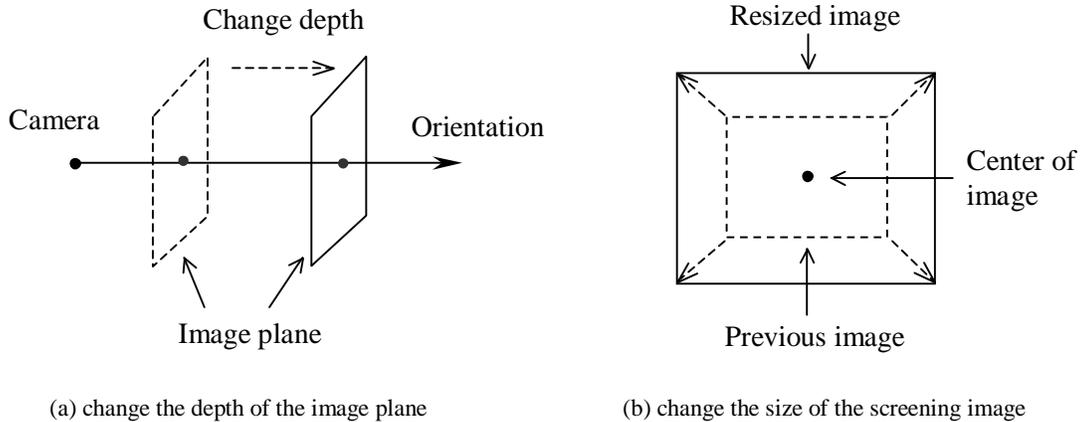


Figure 5. Two extended functionalities of our CT screening tool

## 5. EXPERIMENTAL RESULTS

We have successfully implemented electronic biopsy as a supplementary tool of our virtual colonoscopy system on both 16-processor SGI Challenge and PC Pentium III. Interactive rendering rates of more than 10 frames per second have been reached on both platforms due to our fast ray-casting algorithm. We have applied our virtual biopsy to 13 suspected abnormalities visualized during the virtual fly-through navigation inside the colon CT data sets of 8 patients and 2 volunteers. The density distribution as shown by color and opacity was used to classify the following patterns: uniform or speckled high-density pattern, uniform low-density pattern, and intermediate density pattern, corresponding to stool, hyperplastic polyp, and polyp. These pattern categories were compared to pathological biopsy results and optical colonoscopy findings. We visualized the interior structure of all 13 suspected abnormalities, and determined that six of them are polyps (Fig. 2 shows one of them) and the remaining seven are residual stool balls. Our results were confirmed with the corresponding optical colonoscopy and pathological biopsy findings.

## 6. CONCLUSIONS

We presented an interactive electronic biopsy technique that is capable of displaying the important interior structures of polyps by interactively changing the transfer function, in order to distinguish different kinds of polyps from leftover stool inside the human colon. An interactive graphics user interface, a fast ray casting optimization, and an accurate 2D screening tool are developed for the physician to conveniently modify the transfer function, obtain immediate visual feedback, and confirm the discovery with the original CT data. Compared with the traditional biopsy in the procedure of optical colonoscopy, our method is more flexible, noninvasive, and therefore without risk.

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