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An Image Processing and Visualization System for Virtual Colonography

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Abstract. We describe a system for CT colonography partially based on ray-casting hardware. Offering different presentation approaches, this system enables quick and accurate diagnostic reading. Furthermore, facilities for digital cleansing and computer aided diagnosis have been added. Results obtained from a 100 patients study, employing this system, are highlighted.

1 Introduction

Colorectal carcinoma is the fourth most common cancer and the second leading cause of cancer-related death in the industrialized world [1], with a 4-6% lifetime risk in the general population [2]. Due to this fact screening for colorectal malignancy has to be taken into consideration. Screening based on normal colonoscopy is rather complex and invasive. It needs colonic cleansing and it depends on operator experience. For these reasons the need for less invasive, faster and cheaper procedures for colonic screening has arisen.

Virtual colonography is a promising new technique for exploring the colonic area hinging on volumetric image data. The acquired data can be visualized using either virtual endoscopy or Axial 3D methods. Virtual endoscopy combines volumetric data with computer graphics to simulate views given by a real endoscope. Axial 3D (Figure 1) is based on 3D parallel rendering to generate an exoscopic visualization of the colon and its surrounding tissue. At the moment most of the visualization research and commercially available systems (Siemens, Philips, GE, Viatronix) are focusing on endoscopic like views, or variations of that [3].

One drawback of CT colonography is that the technique requires the same patient preparation as normal colonoscopy. To improve patient acceptability it would be preferable to do fecal tagging combined with digital cleansing. One possibility for this is to administer oral barium or an iodinated contrast agent [4][5], which would mix with the intestinal contents as it passes through the small bowel. If the mix is uniform than a difference in attenuation is obtained between the contrast mixed colonic contents and the colonic mucosa. As a result, theoretically the colonic contents can be subtracted to reveal the underlying structures.

Another problem in the case of large-scale studies is the huge amount of data to be analyzed by radiologists. To solve this problem we are investigating Computer Aided Diagnosis methods [6], which reduce the amount of work and the reading time by presenting only sub-volumes of interest with a high probability of containing polyps.

2 A system for visualization and processing of colonographic image volumes

We are developing a PC based system for visualization and processing of colonographic image volumes. Currently it is implemented on a Windows NT machine (Pentium III 533 MHz, 512 MB RAM, ATI Rage 128 32MB graphics card and Volume Pro 500 ray-casting card).

First a description of the system's basic architecture is given. Then visualization features are highlighted. Finally additional image processing facilities are discussed.

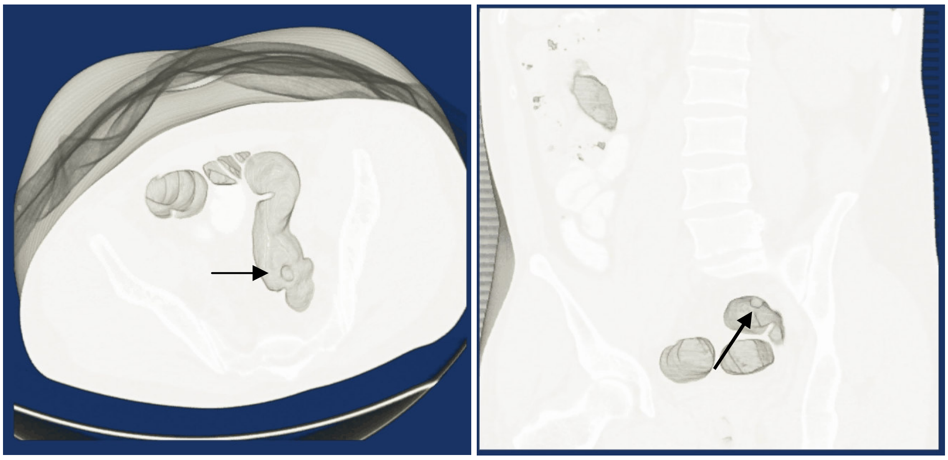

Fig. 1. Axial 3D views, both presenting the same polyp but from different directions. On the left an image from a feet to head walk-through is presented, while on the right an image from an anterior to posterior walk-through is shown. In our system such Axial 3D views are captured as digital movies.

2.1 Architecture

From a software point of view, our system is built around VTK (the Visualization Toolkit, [7]). All user-interfacing functionalities are implemented in an Itcl/Itk extension of VTK's Tcl/Tk wrapper. Those image-processing routines, that are not available in VTK's core, are coded in C++, thus extending the VTK's class hierarchy.

From a hardware point of view, volume rendering is achieved by the use of a Volume Pro 500 card [8]. This ray-casting hardware for PCI bus systems employs a shear wrap algorithm to allow a graphics card to render 256^3 voxels (16 bit) in real time. Its driving software is also encapsulated by VTK, hence providing a smooth integration.

2.2 Visualization features

The main visualization features of the system are: 2D axial viewers, 3D ortho-viewers, volume visualization and digital movie generation using the Axial 3D approach.

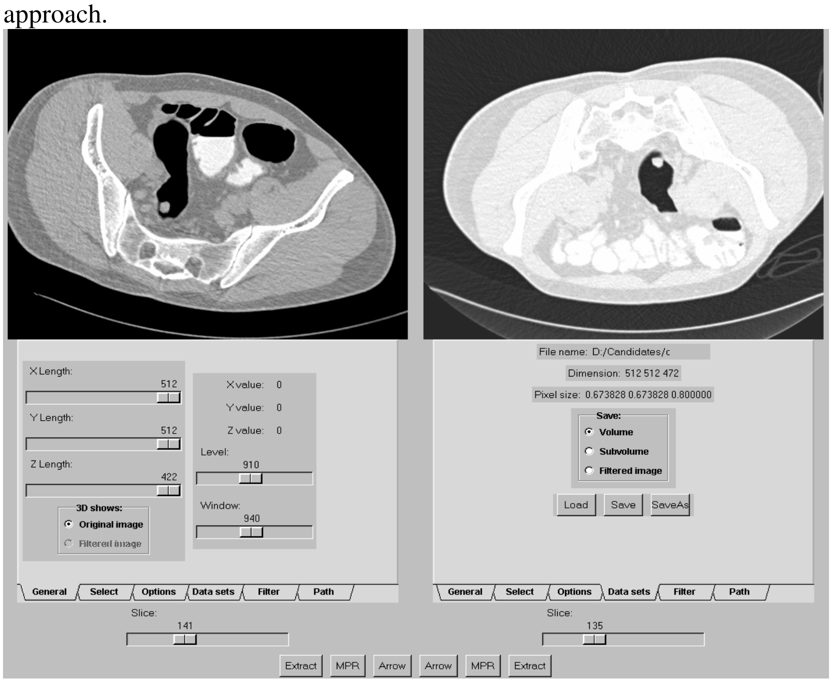

Fig. 2. Snapshot of the 2D axial viewer. The axial viewer shows the same polyp in both prone and supine positions. Different visualizations (volume visualization, multi planar reslice, or arrow pointing out) and image processing can be applied to the two data volumes, from here.

The 2D axial viewer (Figure 2) is the initial window that pops up after patient data has been loaded. It is designed to handle two image data sets, one for prone and one for supine position. The user can scroll through the data sets slice by slice, can set window/level, can select the values for the digital cleansing and the path searching operations (to be discussed in 2.3). For path searching we offer two alternatives, one in which the user indicates a start and an end point and the path in between these points is automatically computed. Alternatively the user can select a path made out of discrete points and then a spline interpolation is applied. Measurements along the path are possible. Using the arrow function the user can point towards a structure of interest and then visualize in 3D the data with the camera pointing towards that structure. The user can also define sub-volumes of interest in order to reduce the amount of data to be visualized.

The 3D ortho-viewer (Figure 3) is used to reconstruct the volume after one of the radiological planes (axial, sagittal and coronal). Possibilities for measurements, zooming, panning and window/leveling (global or separate for each view) are present. The 3D otho-viewer was easily implemented using only classes from the VTK core.

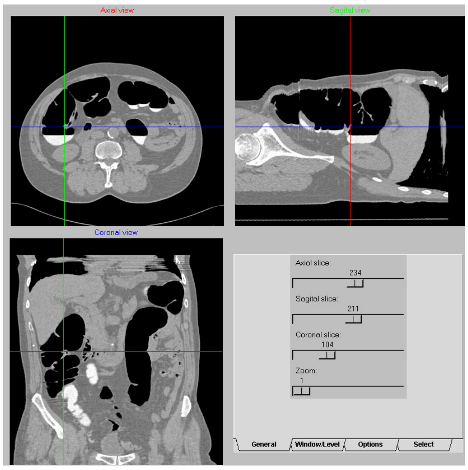

Fig. 3. The 3D ortho-viewers.

The volume rendering (Figure 4) is the most important visualization part of the system. Here the user can do an Axial 3D walk through using an arbitrary plane. This Axial 3D walk-through (Figure 1) consists in peeling of successively slices from the volume data. Path following is available using the path defined in a previous step. Camera parameters like position, focal point, shading or ambient, diffuse and specular coefficients can be modified. The user can select a desired opacity or color transfer

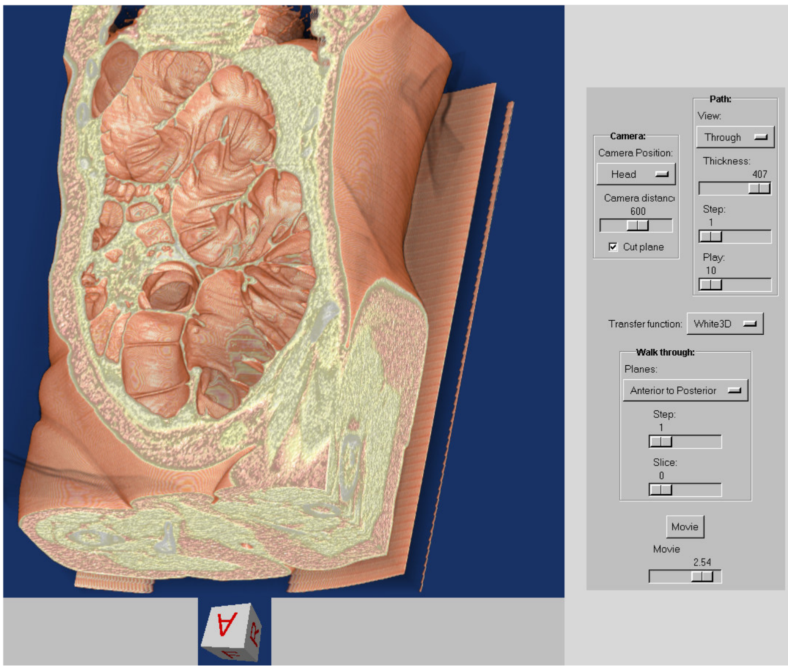

Fig. 4. The volume visualization module, parameters for camera, transfer functions, Axial 3D walk-through and path following are easily specified.

function. For the color transfer function specification we offer two alternatives one in which colors are chosen from a predefined set of colors and second in which each color is composed using the three basic colors (RGB). Defined transfer functions can be stored and reused.

The time required by the system to load a data set is between 3 and 5 minutes. Also the volume rendering for large data sets is not done in real-time, one of the main problems here is that in the current versions of the Volume Pro drivers, the inherent ActiveSubVolume feature is not implemented. While this is acceptable for a small number of cases it is not desired for large-scale studies. That is why we had to look for different presentation approaches. One possible solution is the automatic generation of digital movies stored in AVI files. The advantages of digital movies are fastness, fully automatic generation, possibility of measurements, reusability and clinical relevancy. For our study we used this alternative and for each patient ten Axial 3D movies were generated, these were head to feet, feet to head, anterior to posterior, posterior to anterior walk trough's plus axial slices in normal window done for prone and supine position (see Figure 1). Also an existing AVI viewer was extended to allow slice by slice viewing and to offer possibilities for measurements on the generated movies.

2.3 Image processing algorithms

The image processing algorithms are responsible for digital cleansing, path computation and Computer Aided Diagnosis (CAD). As mentioned they are implemented as extensions of the VTK class hierarchy.

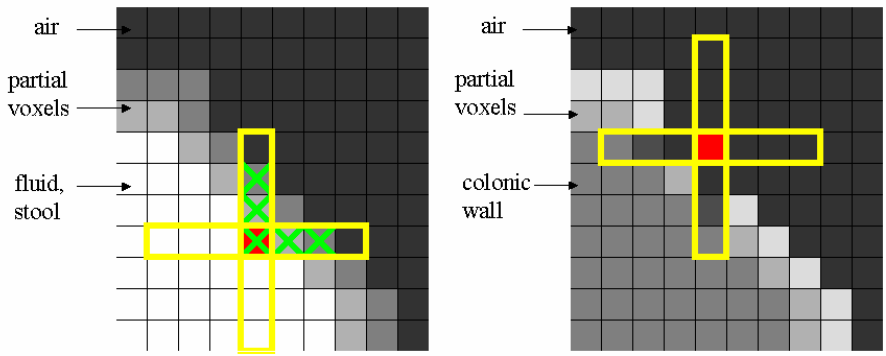

Fig.5. The figure illustrates the two steps of our digital cleansing algorithm, partial voxels at the fluid-air boundary are removed (left), meanwhile partial voxels at the fluid-colonic wall boundary are reconstructed (right).

By **digital cleansing** we understand the removal of fluid or tagged fecal material from the acquired data. Electronic cleansing is available in the Virtual Colonoscopy Module from Viatronix but it is mainly used for fluid cleansing [9]. The simplest approach for digital cleansing is thresholding, but partial voxels at the boundary between tagged fluid/stool-air and tagged fluid/stool-colon are the main problem in this case. The formers have to be removed, while the latter have to be updated. We developed a two-stage filter for digital cleansing, intended to be used for fluid and also fecal cleansing. First the filter detects voxels that belong to tagged fluid or stool and than removes all the partial voxels within a given neighborhood. Second, it reconstructs the colonic wall in this way modifying the partial voxels from the tagged fluid/stool–colonic wall boundary. Figure 5 summarizes the two steps of our filter.

A more classical alternative to Axial 3D is **path following**, this offers views similar to colonoscopy. At the moment our system does not offer endoscopic views due to the lack of perspective rendering of the Volume Pro card. Although perspective projection can be simulated using Volume Pro [10][11] we have chosen Axial 3D for our 100 patient validation, due to its simplicity and efficiency. Nevertheless we have experimented with path searching as well, applying A* search and minimal path computation. After a path is computed a good camera orientation vector and a good view-up vector are needed. We adopted the approach detailed in [12] by letting the camera point towards the furthest path point visible from the current location. In this way the influence of local path variations on camera orientation is minimized. The view-up vector is chosen in order to minimize the camera twisting. A comprehensive presentation of path searching techniques can be found in [13].

The final goal of virtual colonograpy is large-scale screening. The screening procedure will generate more images than radiologists can handle. One way of solving this is **Computer Aided Diagnosis**, which has the potential to reduce the time/patient ratio. The ultimate goal would be automatic polyp detection without any human assistance. An achievable goal at this moment is the detection of interesting regions, regions that have a high probability of containing polyps. Some approaches can be surface curvature methods, surface normal methods and sphere fitting. Our approach [6] is a combination between surface normal and sphere fitting methods. The main steps are segmentation, polyp candidate generation, polyp center generation and finally polyp extraction and presentation.

3 Results

Based on the system described, one of the authors (M.T.) did a study on 100 patients using conventional colonoscopy as ground truth. For each patient he mainly used 6 from the 10 movies generated. The anterior to posterior walk-through and posterior to anterior walk-trough were used only as problem solving. He reported [14] a sensitivity of 87% for polyps larger than 9mm, 54% for polyps between 6-9 mm and 25% for polyps smaller than 5 mm. The obtained specificity was 100% for polyps larger than 9mm, 92% for polyps between 6-9 mm and 27% for polyps smaller than 5 mm. His results are comparable to those reported by other authors [17][18].

We have tested our digital cleansing technique on patients for which wet preparation/fluid tagging was used and also on patients with dry preparation/stool tagging. Usually fluid can be detected easier than stool because it is mostly horizontal. Fluid cleansing does no visible tissue damage, but a characteristic ring on the colonic wall at the fluid-air boundary is visible. Figure 6 shows two Axial 3D renderings one with fluid and one after digital cleansing. The quality of the cleansed colonic region is quite similar to original colonic tissue.

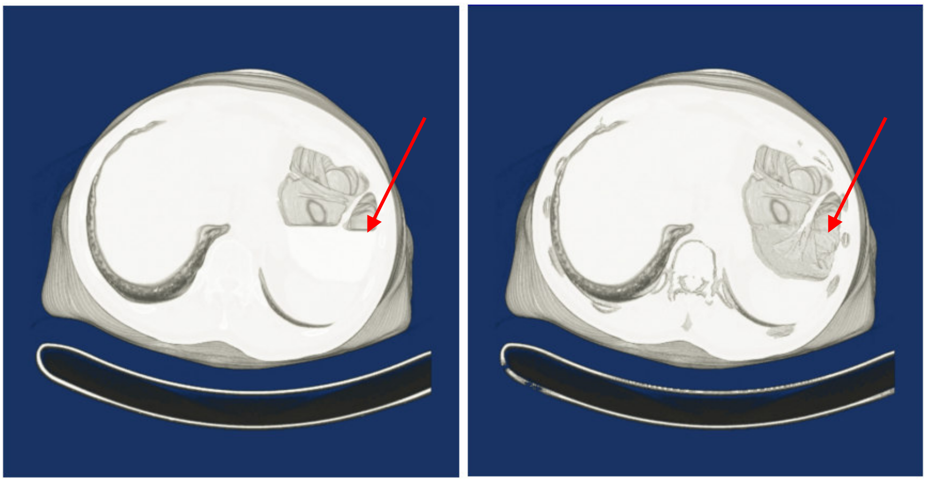

Fig. 6. Axial 3D renderings of fluid filled (left) and digitally cleansed (right) colon.

In case of the fecal cleansing, removal of some haustral folds was visible, the reason for this is that thin haustral folds are considered partial voxels. A second problem in this case is that the cleansed colonic surface looses its natural smoothness.

We have applied our CAD method [6] to 18 patients, 9 positives and 9 negatives. Our method detected all nine polyps of 10mm or larger, 1 from 2 polyps of 6mm, 1 from 3 polyps of 5 mm.

4 Conclusion and discussion

We can conclude that virtual colonograpy is worth while doing on a normal PC given appropriate visualization hardware is available. Axial 3D is a viable alternative to virtual colonoscopy, giving reading results similar to path following approaches. Also it is faster than path following because no path computation is needed. We believe that Axial 3D is even a better approach because it presents surrounding tissue as well as colonic wall. We found digital movies to be faster than real-time visualization, clinically useful but apart from measurements they do not offer any interactivity. The loss of interactivity can be compensated by the generation of movies after different directions (anterior to posterior and posterior to anterior) for problem solving.

From the literature [15][16] we can say that at the moment patient acceptability is the same for virtual colonoscopy as for normal colonoscopy. This is largely due to the patient preparation, which at the moment is similar for the two procedures. To promote virtual colonography as a screening tool patient acceptability has to be improved. One way of doing this is to use dry preparation/fecal tagging combined with digital cleansing.

CAD is probably the future of virtual colonography, and it will be the most common way of doing CT- colonography especially in the case of large-scale screenings. Our initial results show that reading time can be heavily decreased using CAD and also that CAD can accurately detect significant polyps. Further testing though is needed to evaluate the sensitivity of this kind of algorithms on larger patient databases. Also the impact of acquisition parameters on sensitivity and specificity has to be further evaluated.

Acknowledgement

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