Development of a Navigation-Based CAD System for Colon

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Abstract. We propose a navigation-based computer aided diagnosis (CAD) system for the colon. When diagnosing the colon using virtual colonoscopy (VC), a physician makes a diagnosis by navigating (flying-through) the colon. However, the viewpoints and the viewing directions must be changed many times because the colon is a very long and winding organ with many folds. This is a time-consuming task for physicians. We propose a new *navigation-based* CAD system for the colon providing virtual unfolded (VU) views, which enables physicians to observe a large area of the colonic wall at a glance. This system generates VU, VC, and CT slice views that are perfectly synchronized. Polyp candidates, which are detected automatically, are overlaid on them. We applied the system to abdominal CT images. The experimental results showed that the system effectively generates VU views for observing colon regions.

1 Introduction

In Japan, the number of patients suffering from colonic cancer is increasing. Colonic cancer can be cured completely if it is found in its early stage, i.e., colonic polyps. However, if found in its latter stages, a complete cure is difficult due to metastasis. Therefore, screening of the colon for early detection of colonic polyps is important. Colonoscopy, which is mainly performed in the clinical field, is physically and mentally painful for patients. Furthermore, some problems are

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that a physician needs much skill and experience to operate the colonoscope, and it is time-consuming task due to the long and winding shape of the colon, which has many folds.

In the clinical field, virtual colonoscopy (VC) is a new diagnostic tool that is considered less-invasive, due to development of imaging devices such as multi detector-row (MD) CT scanners. VC provides a virtual environment of the colon based on 3D CT images of a patient and visualizes the inside of the colon everywhere a physician wants to observe. The CT images on a computer can be regarded as the virtual human body of a real patient. A physician can diagnose the virtual human body while doing a fly-through the inside of it. We call this diagnostic scheme *navigation diagnosis.* However, because the colon has a complicated shape, a physician has to change viewpoints and viewing directions many times. Thus, VC is still a time-consuming task. Therefore, a computer aided diagnosis (CAD) system must be developed for the colon that has various functions to assist physicians such as automated polyp detection and "easy to observe" visualization, e.g., unfolded views of the colon.

Automated polyp detection has been researched by several groups [1, 2, 3, 4, 5]. They used curvature or intensity distribution information of colonic polyps. Each method developed by them can detect polyps with high sensitivity, but false positives also detected. Ways to reduce the false positives are being researched now. Another important function for CAD is visualization. Even if CAD could accurately detect polyp candidates, final decisions should be made by physicians no matter how they use CAD. Therefore, we should also think about how to efficiently visualize the colon. One possible solution is unfolding the colon.

Several studies have examined the virtual unfolding of the colon [6, 7, 8]. The unfolding must (1) be less distorted, (2) give a real-time rendering of the unfolded views and (3) unfold using arbitrary cutting. Our system focuses on requirements (2) and (3) to make diagnoses using CAD efficient.

The CAD system we propose here has automated polyp detection and real-time visualization of unfolded views of the colon. A special characteristic of our system is that three kinds of views are completely synchronized, i.e., ordinary CT slice view, VC view and virtual unfolded (VU) view. For example, if a physician finds a suspicious area in a VU view, he/she can seamlessly check it on both the VC and CT slice views.

In Section 2, we describe the navigation-based CAD system we developed. Experimental results of polyp detection and virtual unfolding are shown in Section 3. A brief discussion is in Section 4.

2   Navigation-Based CAD System for the Colon

2.1   Overview

For a CAD system for the colon, functions that assist physicians such as automated polyp detection, navigation to suspicious areas, and "easy to observe" visualization to reduce the inspection time are important. Because physicians diagnose patients' CT data by flying through their virtual bodies, we call a CAD
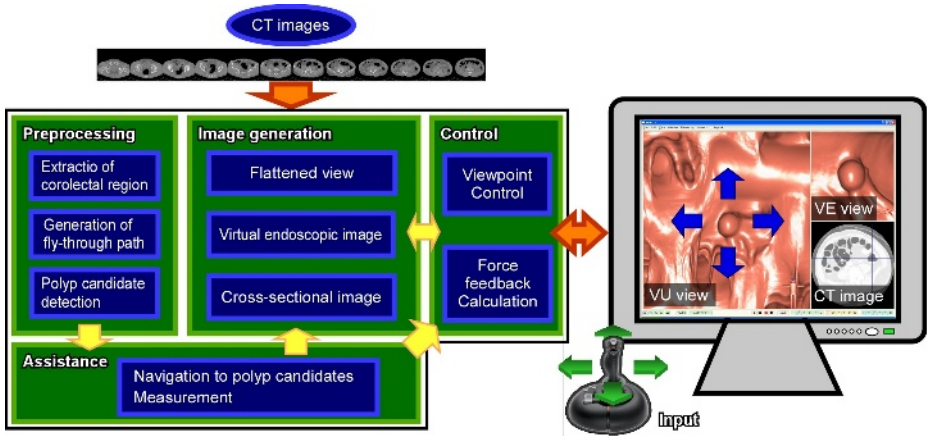
Fig. 1. Overview of navigation-based CAD system

system that uses this technique a *navigation-based CAD system*. Our system consists of four parts: (a) preprocessing, (b) image generation, (c) system control, and (d) observation assistance. An overview of the system is shown in Fig. 1.

The preprocessing part generates a central line of the colon for navigation and unfolding. Polyp candidates are also detected here. The image generation part generates VC, VU, and CT slice views. These views are synchronized by the control part. The system control part also allows physicians to navigate to polyp candidates detected in the preprocessing part. Of course, physicians can fly-through inside the colon freely using intuitive input devices such as joysticks. We explain each part below.

2.2 Preprocessing

Central line generation. First, we extract a colonic lumen region using a region-growing method. Then, we generate a central line from the lumen region.

(1) Extraction of colonic lumen region. A colonic lumen region is segmented using a region-growing method (Fig. 2 (a)). CT values of a lumen are defined by -1000 to -700 H.U..

(2) Thinning and spurious branch elimination. A thinning algorithm [9] is applied to extract the central line of a colonic lumen region. A thinning result is shown in Fig. 2 (b). As you see, many spurious branches remain after the thinning process. Those spurious branches are eliminated by calculating the minimal path between the farthest two points on the thinned figure (Fig. 2 (c)).

(3) Central line generation using spline interpolation. A central line is generated using cubic spline interpolation as follows. First, control points $\mathbf{P}_k(k = 0, ..., N)$ are allocated at intervals of 20 voxels on the thinned figure. Then, the central line is obtained using cubic spline interpolation from $\mathbf{P}_k$ (Fig. 2 (d)). Points on the central line are denoted as $\mathbf{p}_i(i = 0, ..., M)$.
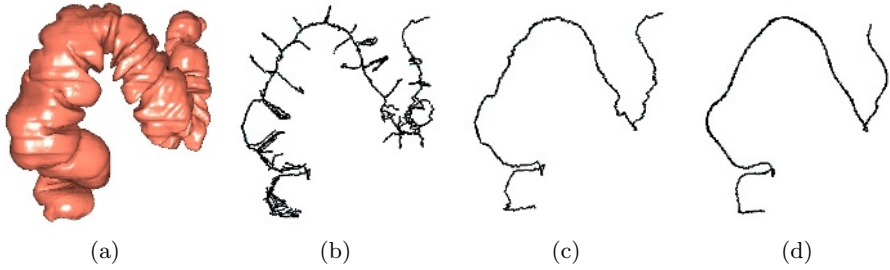
Fig. 2. Generation of central line of colon. (a) Extracted lumen region, (b) result of thinning, (c) result of spurious branch elimination, and (d) generated central line.

Polyp candidate detection. Polyp candidates are detected using a detection method [5]. Convex regions on the colonic wall are detected as polyp candidates. The shape index and curvedness, which are calculated from curvatures on the colonic wall, are used for shape classification. See Kitasaka et al. [5] for details.

2.3   Image Generation

In this part, VC, VU, and CT slice views are generated. The VU view is generated by controlling ray-casting directions in the volume rendering.
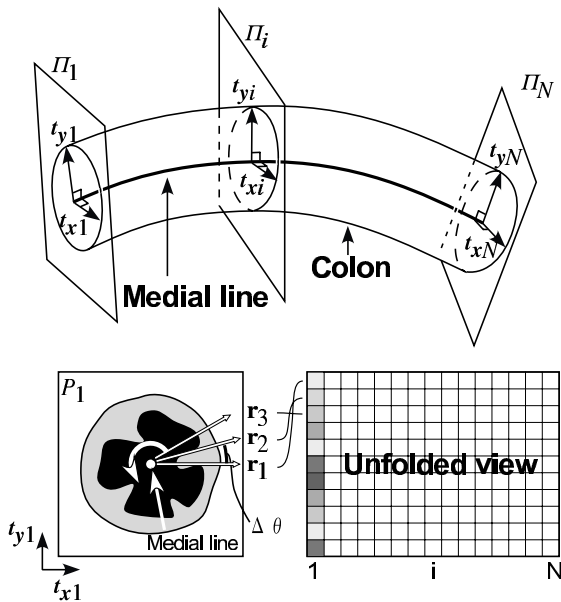
Fig. 3. Schematic illustration of unfolding process

Virtual unfolding view. For each point on the central line $\mathbf{p}_i$, a ray is casted along a direction vertical to the tangent, $\mathbf{t}_i$, of the central line at the voxel. Let $\mathbf{t}_{\mathbf{x}i}$ be a vector perpendicular to $\mathbf{t}_i$, and $\mathbf{t}_{\mathbf{y}i}$ be the vector perpendicular to both $\mathbf{t}_i$ and $\mathbf{t}_{\mathbf{x}i}$. Then, casting directions $\mathbf{r}_j^i(0 \leq j \leq m; m = 2\pi/\Delta\theta)$ at $\mathbf{p}_i$ are defined by

$$\mathbf{r}_j^i = \mathbf{t}_{\mathbf{x}i} \, cos(j\Delta\theta) + \mathbf{t}_{\mathbf{y}i} \, sin(j\Delta\theta). \tag{1}$$

That is, a VU view is generated by casting rays on an orthogonal plane, Π_i, toward the colonic wall side at each point, $\mathbf{p}_i$, on the central line (Fig. 3). Because this unfolding is equivalent to a volumetric deformation, we can observe not only the surface of the colonic wall but also blood vessels beyond the wall on a VU view by adjusting rendering parameters (color, opacity, etc.).

2.4   System Control

This system uses a joystick as an intuitive input device. When the stick is inclined right and left, the camera moves forward and backward along the central line. When the stick is inclined back and forth, the VU view is rotated along the central line; i.e., the cutting line of the colon is modifiable.

2.5   Observation Assistance

This part is to assist observation and diagnosis by synchronizing views and coloring polyp candidates detected automatically and unobserved regions.

Synchronized views. Let $\mathbf{p}_i$ be the point on the central line at the center of a VU view. VU, VC, and CT slice views are synchronized as follows. In the VC view, the viewpoint is the same as $\mathbf{p}_i$, and the view direction is set as $\mathbf{r}_{m/2}^i$ (the vector that points to the center of the VU view). The CT slice that contains $\mathbf{p}_i$ is displayed.

Colored polyp candidates and unobserved regions. Polyp candidates are overlaid on VU views and VC and a CT slice views. Because of the complicated shape of the colon, polyps may be overlooked. Thus, our system detects unobserved regions [10]. Physicians are shown which parts they have not observed yet. Polyp candidates can be navigated to.

3   Experiments

We implemented the navigation-based CAD system on a PC platform (CPU: Intel Xeon 3.6GHz, Memory: 2GByte). Four cases of the colonic wall were unfolded by the system. The acquisition parameters of the CT data are: 512×512 pixels, 0.586 - 0.781 mm/pixel, 333 - 370 slices, 1.0 - 2.5 mm slice thickness, and 1.0 - 1.25 mm reconstruction intervals.

The results of the central line extraction are shown in Fig. 4. Examples of unfolding are shown in Fig. 5. System overviews are shown in Fig. 6. The top,
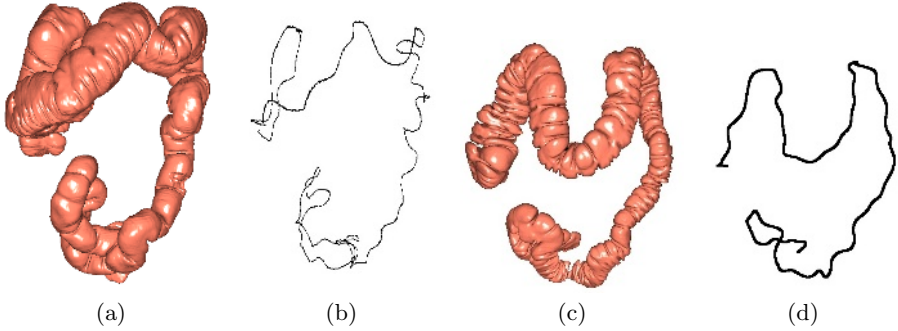
Fig. 4. Results of central line generation. (a) Extracted lumen of Case 2, (b) central line generated from (a), (c) extracted lumen of Case 3, and (d) central line generated from (c).

Table 1. Ray intersection percentages

Case	Ray intersection (%)
1	24.56
2	33.34
3	19.41
4	13.74

left-bottom, and right-bottom views are the VU, VC, and CT slice views. Polyp candidates detected by the system are colored blue. In Fig. 6 (b), blood vessels beyond the colonic wall can be observed. During VU view generation, some rays cast from the central line intersect each other before they hit the colonic wall. The percentages of rays that intersect are shown in Table 1. The rendering speed, including the unfolding process, was approximately 0.1 second per frame. The rendering resolutions of VU and VC views are 256×256 and 256×256.

4   Discussion

Our system can unfold the colon in real-time. As shown in Fig. 5, haustra are clearly distinguished in VU views. However, we found that areas near sharp bends are distorted. Rays intersected in such areas. As shown in Table 1, rays intersected in all cases. As a consequence, a polyp may appear more than once on the VU view, or a part of a polyp may switch its position with another part of the colonic wall. To reduce this distortion, ray intersection must be reduced. This subject will be addressed in future work.

As shown in Fig. 6, physicians can easily find polyp candidates in the VU view and verify them on both the VC and CT slice views. Those three views are completely synchronized in real-time. This allows physicians to feel free to observe, i.e., comfortably navigate the colon. Furthermore, blood vessels beyond the colonic wall can be observed in the VU view. The unfolding process used in
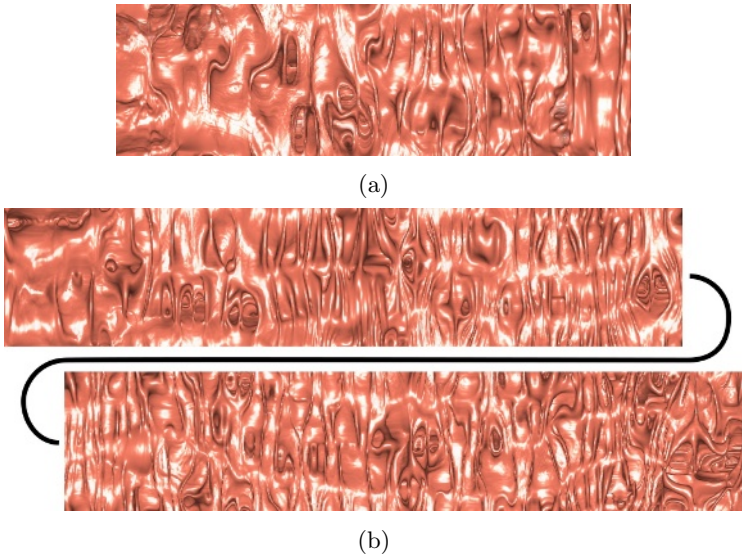
(a)

(b)

Fig. 5. Results of unfolding of colon. (a) Case 1 and (b) Case 3.
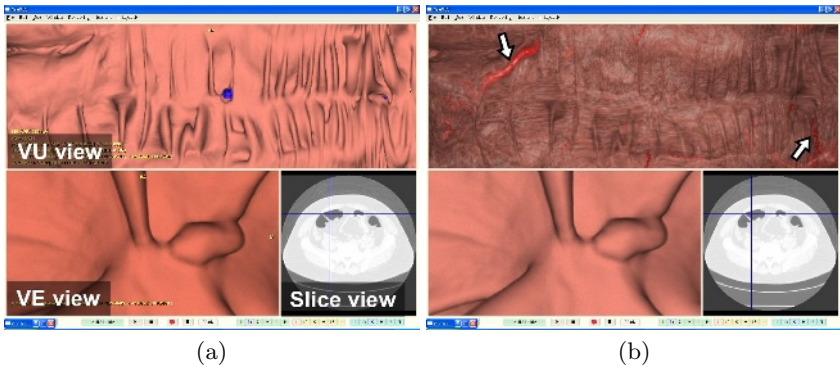

(a)   (b)

Fig. 6. Example of polyp candidate detection and its display in VU view for Case 3. Blood vessels are observed in VU view by changing transparency of colonic wall, indicated by arrows.

the system volumetrically deforms the colon simply by controlling the directions of ray-casting, so we can observe not only the surface of the colonic wall but also beyond the wall by changing the rendering parameters.

5   Conclusion

We proposed a navigation-based CAD system for the colon. This system has functions to assist physicians; automated polyp detection, virtual unfolding, and

synchronized VU, VC, and CT slice views. We applied the navigation-based CAD system to four cases of 3D abdominal CT data. By comparing synchronized VU and VC views, we observed the entire colonic wall efficiently. Future work includes further experiments using larger number of CT data, evaluations by physicians, and reduction of distortion in VU views.

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