DEVELOPMENT OF A COMPUTER AIDED DIAGNOSIS SYSTEM FOR COLORECTAL CANCER BASED ON NAVIGATION DIAGNOSIS

Masahiro Oda, Takayuki Kitasaka, Kensaku Mori, Yasuhito Suenaga

Graduate School of Information Science, Nagoya University

ABSTRACT

Recently, virtual colonoscopy (VC) has received attention as a new colon diagnostic method. VC is considered a less invasive inspection and reduces diagnosing time. However, because the colon has many folds and its shape is long and convoluted, a physician has to repeatedly change viewpoints and viewing directions many times. We propose a new computer aided diagnosis (CAD) system for the colorectal cancer providing virtual unfolded (VU) views, which enables physicians to observe a large area of the colonic wall at a glance. This system generates VU, virtual endoscopic (VE), and CT slice views that are perfectly synchronized. Polyp candidates, which are detected automatically, are overlaid on them. We implemented the proposed system on a PC platform and observed abdominal CT images. The experimental results showed that the system effectively generates VU views for observing colon regions.

1. INTRODUCTION

Recently, the number of people suffering from colonic cancer is increasing in Japan. Early stage detection of colonic cancer can result in a complete cure. Colonoscopy and barium enema, mainly performed as colon inspection methods in clinical fields, are physically and mentally painful for patients and take a lot of time when diagnosed. Therefore, the load of patients when these methods are performed in periodic inspection is a problem.

In the clinical field, virtual colonoscopy (VC) is a new diagnostic tool that is considered less-invasive. 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.

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, virtual endoscopic (VE) view and virtual unfolded (VU) view.

2. 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 system that uses this technique a *navigation-based CAD system*. Our system consists of four parts: preprocessing, image generation, system control, and observation assistance.

2.2. Generation of less-distorted VU views

Several studies have reported on generation of VU views of the colon [1-3]. We also have already proposed a generation method of a VU view in real time by using software-based volume rendering [4]. We generated VU views by controlling ray directions of volume rendering. Rays were cast along a plane which is perpendicular to the centerline of the colon. This method had a problem that rays intersect each other at sharp bending areas of the colon. Also planes, which are perpendicular to the centerline and on which rays exist, intersect each other near sharp bending areas (Fig. 1). It causes spurious holes on VU views. We reduce the ray intersections by employing a spring model. It allocates springs between planes perpendicular to the centerline. Then plane directions are modified by spring forces, which lead to reduction of the intersections of the planes as shown in Fig. 2.

We extract a colon lumen region from abdominal CT images by a region growing method. Then, a thinning algorithm is applied to the extracted lumen region to extract a centerline. We allocate points on the centerline at predefined interval. These points are denoted as $\mathbf{p}^i$ (i = 0,...,I). Then, we allocate planes Π^i that are passing though $\mathbf{p}^i$ and are perpendicular to the centerline. Here, I is the total number of points allocated on the centerline. Superscript i is the index of the points and the planes. Average distances a^i from $\mathbf{p}^i$ to the colonic wall are calculated on the Π^i. On Π^i, we allocate nodes $\mathbf{v}^i_j$ (j = 0,...,J-1) at the positions that are a^i away from $\mathbf{p}^i$. Here J is the total number of nodes allocated on each Π^i. Springs are spanned between nodes $\mathbf{v}^i_j$ and $\mathbf{v}^{i+1}_j$ as shown in Fig. 3.

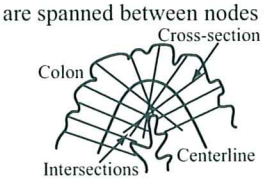

Fig. 1 Intersection of planes perpendicular to the centerline of the colon.

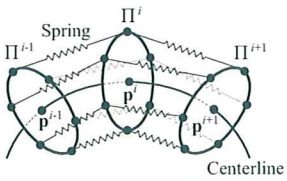

Fig. 3 Allocation of nodes and springs.

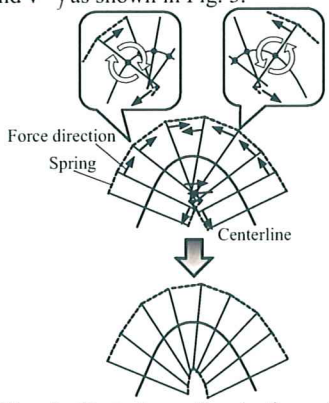

Fig. 2 Illustration of reduction of intersected areas of planes using a node-spring model.

The direction of each Π^i is modified according to the forces working on the planes. Two springs, between $\mathbf{v}^i_j$ and $\mathbf{v}^{i-1}_j$ and between $\mathbf{v}^i_j$ and $\mathbf{v}^{i+1}_j$, are connected to a node $\mathbf{v}^i_j$. So the resultant force working at this node is described as

$$\mathbf{F}^i_j = \mathbf{G}^{i,i-1}_j + \mathbf{G}^{i,i+1}_j, \quad (1)$$

where $\mathbf{G}^{i,i+1}_j$ represents the spring force from a spring between $\mathbf{v}^i_j$ and $\mathbf{v}^{i+1}_j$,

$$\mathbf{G}^{i,i+1}_j = k\left(\left|\mathbf{T}^{i,i+1}_j\right| - l\right)\mathbf{T}^{i,i+1}_j \Big/ \left|\mathbf{T}^{i,i+1}_j\right|, \quad (2)$$

where $\mathbf{T}^{i,i+1}_j = \mathbf{v}^{i+1}_j - \mathbf{v}^i_j$. k is the constant of a spring. The natural length of springs is denoted as l. The direction of the plane is moved to the direction of the moment of forces working on the plane. An iterative process is utilized in this process. The iteration is terminated if the number of iteration reaches at the predefined value.

2.3. 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 centerline. When the stick is inclined back and forth, the VU view is rotated along the centerline; i.e., the cutting line of the colon is modifiable.

2.4. 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 centerline at the center of a VU view. VU, VE, and CT slice views are synchronized as follows. In the VE view, the viewpoint is the same as $\mathbf{p}^i$, and the view direction is 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, VE, and CT slice views. Because of the complicated shape of the colon, polyps may be overlooked. Thus, our system detects unobserved regions [5]. Physicians are shown which parts they have not observed yet. Polyp candidates can be navigated to.

3. EXPERIMENTS

We implemented the proposed system on a PC platform (CPU: Intel Dual-Core Xeon 2.8GHz x 2, Memory: 4GByte). Eighteen cases of the colonic wall were unfolded by the system. The acquisition parameters of the CT data are: 512 x 512 pixels, 0.35 - 0.78 mm/pixel, 33 - 465 slices, 1.00 - 10.00 mm slice thickness, and 0.62 - 10.00 mm reconstruction intervals. Parameters in VU views generation are set as J=6, k=0.0003, and l=0. We set the upper limit of the iteration of the plane direction modification process as 10000 times. Fig. 4 shows VU views generated by the previous method and the ones obtained by the proposed method. System overviews are shown in Fig. 5. The top, left-bottom, center-bottom, and right-bottom views are the VU VE, outside, and CT slice views. A polyp candidate detected by the system is colored blue. In Fig. 5 (b), blood vessels beyond the colonic wall can be observed.

4. DISCUSSION

Our system can unfold the colon in real-time. As shown in Fig. 4, haustra are clearly distinguished on VU views. As comparing VU views between before and after reduction of ray intersection on Fig. 4 (a) and Fig. 4 (b), spurious holes were significantly reduced. Average of intersection rate decreased 20.0% to 5.1% after utilization of the intersection reduction process.

As shown in Fig. 5, physicians can easily find polyp candidates in the VU view and verify them on both the VE 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 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, VE, and CT slice views. We applied the navigation-based CAD system to eighteen cases of 3D abdominal CT data. By comparing synchronized VU and VE views, we observed the entire colonic wall efficiently. Future work includes further experiments using larger number of CT data, evaluations by physicians, and further reduction of distortion in the VU views.

6. REFERENCES

[1] G. Wang, E.G. McFarland, B.P. Brown, and M.W. Vannier, "GI Tract Unraveling with Curved Cross Sections," IEEE Trans. on Medical Imaging, 17(2), pp. 318-322, 1998.

[2] A.V. Bartroli, R. Wegenkittl, A. Konig, and E. Groller, "Virtual Colon Unfolding," Proc. of IEEE Visualization, pp.411-420, 2001.

[3] S. Haker, S. Angenent, A. Tannenbaum, and R. Kikins, "Nondistorting Flattening Maps and the 3-D Visualization of Colon CT Images," IEEE Trans. on Medical Imaging, 19(7), pp. 665-670, 2000.

[4] M. Oda, T. Kitasaka, Y. Hayashi, K. Mori, Y. Suenaga, and J. Toriwaki, "Development of a Navigation-Based CAD System for Colon," MICCAI 2005, LNCS 3749, pp. 696-703.

[5] Y. Hayashi, K. Mori, Y. Suenaga, J. Hasegawa, and J. Toriwaki, "A method for detecting undisplayed regions in virtual colonoscopy and its application to quantitative evaluation of fly-through methods," Academic Radiology, 10, 12, pp. 1380-1391, 2003.

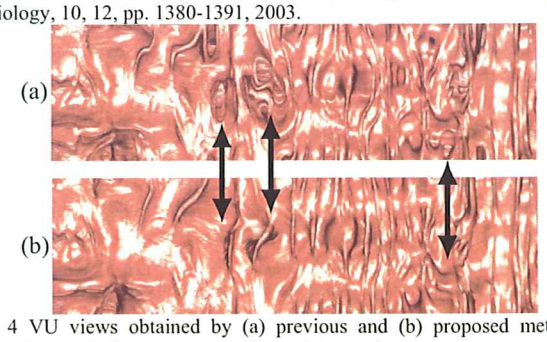

Fig. 4 VU views obtained by (a) previous and (b) proposed methods. Arrows indicate corresponding points on views.

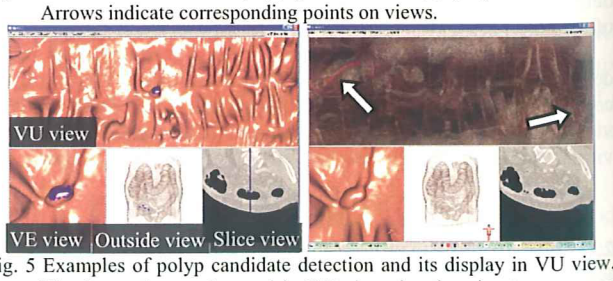

Fig. 5 Examples of polyp candidate detection and its display in VU view. Blood vessels are observed in VU views by changing transparency of colonic wall, indicated by arrows.