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An extension to 3D topological thinning method based on LUT for colon centerline extraction

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ABSTRACT

Topological thinning is a valid but time-consuming method to calculate the centerline of human colon or other hollow organs accurately. An optimized 3D topological thinning method based on Look-up Table (LUT), which was proposed by Sadlier, proves to be effective in improving the efficiency on many occasions. However, it is still inefficient when processing some complex datasets. In this paper, we first analyze the reason causing the unstable performance, and then present an extension to Sadlier's method, which enables the rapid execution of the extraneous loops removing by avoiding unnecessary global connectivity testing. To reach this purpose, a min-heap structure is introduced to select a seed from the candidate voxels set of the final centerline, and region growing technique is used to find the voxels in the same branch with the seed. The comparison among the standard topological thinning, LUT method and the extension to LUT method indicates the extension achieves the most efficient performance.

1. Introduction

Accompanied with the rapid development of the computer and medical photograph technology, improvements in high-resolution computed tomography (CT) and MR acquisition together with advances in 3D reconstruction provided a large clinical potential for virtual endoscopy in the evaluation of any hollow organ system.

Virtual colonoscopy [1–3] is a type of interactive 3D medical imaging tool which combines the features of endoscopic viewing and cross-sectional volumetric imaging. It processes the 3D image data sets from CT or MRI scans using lots of computer methods and rebuilds the 3D structure of the scanned body as well. Thus doctors can operate the rebuilt 3D structure through moving, rotating or zooming (called navigation) to observe the internal structure of the organ. Since it is a non-invasion method, it can avoid the serious side effects such as perforation, infection and hemorrhage caused by real endoscopy.

However, manual navigation through a virtual reality model of colon is a very slow and tedious process. Accordingly people prefer an automated navigation which is performed as follow steps: First, a centerline is generated; Then this centerline can subsequently be used to guide the observer (or virtual camera) through the colon lumen and generate fly-through images of the inside colon.

In this paper, an extension of the LUT method given by Sadleir is presented. First, we summarize the approach to centerline extraction using Look-up Table (LUT) presented by Sadleir. Then we analyze the defect of the algorithm with LUT and describe our improvement as well as the data structure. We reveal implementation and results in Section 5 and finally conclude this paper with the result comparison among the standard way, LUT method and our extension in Section 6.

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2. Background

2.1. Centerline extraction

A centerline extraction algorithm is expected to calculate an approximation of the center path of the colon accurately in a reasonable time. Time constraint is a very important factor to evaluate the algorithm especially in a clinical practice.

Early centerline extraction algorithms were based on a technique called onion peeling [4] or topological thinning. In this method, the surface points of colon are peeled repeatedly until the centerline is obtained. Though the results from this standard algorithm are accurate, it is extremely inefficient. Therefore, researchers recently worked out other methods such as distance transform, minimum energy path etc.

Hassouna and Farag [19] presented a novel framework for computing centerlines for both 2D and 3D shape analysis. In their method, centerline is considered a point source (PS) transmitting a wave front that evolves over time and traverses the object domain. The front propagates at each object point with a speed proportional to its Euclidean distance from the boundary. The motion of the front is governed by a nonlinear partial differential equation whose solution can be computed efficiently using level set methods.

Van Uitert and Bitter [20] presented an automatic algorithm for computing subvoxel precise skeletons of volumetric data by using subvoxel precise distance fields as input and fast marching method to extract the skeleton. It can obtain the skeletons of those objects which are less than a single voxel thick.

There is a brief summary in Table 1, in which we classify centerline extraction methods into three categories. In each category, several representative works are listed.

2.2. Review on LUT method

Sadleir and Whelan [13] provide an optimized version of topological thinning. Considering the deletion of voxels is just a local process, they use Look-Up Table to register whether a voxel with respect to a neighborhood configuration can be deleted. LUT is established before the extraction of centerline and once established, it can be used for any dataset. When testing a voxel in topological thinning, an index of this voxel is generated first. Whether this voxel should be deleted can be determined immediately after querying the LUT. It can successfully avoid testing the local connectivity of every voxel so that the performance will be improved greatly.

For a $3 \times 3 \times 3$ space, the number of possible neighborhood configurations in LUT will be 2^{26}. Each of the configurations has a unique index I, which can be generated as Eq. (1):

$$I = \sum_{n=0}^{25} 2^n V_n \qquad (1)$$

where every bit of this integer V_n represents whether the corresponding voxel is a background one or otherwise. An example of index generation is showed in Fig. 1.

The value referenced by each index is assigned as 1 if this voxel can be deleted, which means that deleting this voxel does not break the local connectivity or introduce a new hole, and 0 otherwise. Fig. 2a shows the case that the connectivity is broken and Fig. 2b shows the case that a new hole is introduced by the deletion.

After reading the segmented result, the centerline extraction algorithm will firstly scan the solid object to specify the surface voxels and insert them into a vector. Then to each element in this vector, the algorithm generates the index using the method described above and checks the returned value from the Look-up Table referenced by this index. If the value is “1”, this element is deleted from the vector. This procedure is repeated until there are no more elements that can be deleted in this vector.

Unfortunately, now the elements in the vector are not the final centerline because it may have some extraneous loops due to the holes in the original segmented colon lumen, which are a common phenomenon associated with the Hasutral

Table 1 – Centerline extraction algorithms published previously.

Category	Authors	Year	Method
Euclidean distance coding/transform	Zhou et al. [5]	1998	Using a distance from surface field to extract skeleton
	Zhou and Toga [6]	1999	Using a distance from source field with cluster centers to find centerline points
	Bitter et al. [7–9]	2001	Using Dijkstra’s shortest path algorithm on a graph built with a combination of distance from a source node and distance from the boundary
Boundary peeling/erosion	Ge et al. [11,12]	1999	3D topological thinning and using graph search algorithm to remove extra loops and branches
	Sadleir et al. [13,14]	2005	Optimized 3D topological thinning using Look-up Table
Hybrid methods	Bouix et al. [15]	2005	Using modified the average outward flux based medial surfaces algorithm to extract the center path
	Deschamps and Cohen [16]	2001	Finding paths of least action in 3D intensity images