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3D navigation of CTVE and correction of MinIP methods in non-invasive diagnostic detection

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Abstract

Navigation is important in Computed Tomography Virtual Endoscopy (CTVE) functions. Existing navigation methods involve planning and pre-calculating of a fixed path before the viewpoint flight inside the targeted organs. This includes path construction, centering, smoothing and multi-branch processing. This paper proposes a 3D navigation method which was achieved by utilizing the compatibility of the 3D navigation and the ray casting 3D rendering method, without the necessity of planning and pre-calculating a fixed path, eliminating the multi-branch problems. In our 3D navigation method, the viewpoint direction and location are tracked in real time when the viewpoint is inside the organs. At the same time it presents and controls the direction changes and location changes of the viewpoint in x, y, z dimensions. With interactive control of the viewpoint, it can fly in any direction in 3D, not only along a fixed path, thus eliminating multi-branch problems. The viewpoint locations and directions will change smoothly and will be used to calculate the current scene of CTVE. Accelerated ray casting is used to render 3D scenes, which is compatible with the 3D navigation method.

In Minimum Intensity Projection (MinIP) applications, if the conventional MinIP reconstruction method is used, realistic results cannot be achieved when they are rotated in multi-directions because the Computed Tomography (CT) images always contain empty regions surrounding the tissue regions. The conventional MinIP reconstruction algorithm always chalks up a minimum intensity voxel which relates to the empty regions instead of the tissue regions. To solve such valid voxel searching problems, seed-filling algorithms are used to fill the empty regions of each slice automatically. The empty voxels are labeled automatically and are avoided in MinIP calculation to gain correct results in all directions.

Keywords: CT; Virtual endoscopy; 3D navigation; Non-invasive detection; Minimum intensity projection; Clinical application

1. Introduction

Changes in the ducts of tissues can be major causes of disease [1]. These ducts include trachea and bronchial airways, bile ducts, colorectal canal and so on. Many specific clinical problems arise in these anatomic ducts, such as trachea and bronchial stenosis, biliary calculi and colorectal polyps. Early detection and removal of lesions is important in preventing progression towards a serious disease [1]. Fortunately, great progress has been made in Computed Tomography (CT) imaging techniques in recent years. Volume scanning and thin slice imaging techniques of Multi-Slice Computed Tomography (MSCT) are widely used; spatial resolution and temporal resolution and density resolution have greatly improved in clinical imaging practice, facilitating the detection of smaller tissue lesions. Based on this technical progress, Computed Tomography Virtual Endoscopy (CTVE) and Minimum Intensity Projection (MinIP) have become more reliable and promising visualization functions in non-invasive diagnostic detections [2,3,9].

Navigation plays an important role in CTVE functions, and great research interest was shown in this area in recent years [7,13–15]. Most existing navigation methods of CTVE involve planning and pre-calculating a fixed path before the flight inside the targeted organs. Centering, smoothing and multi-branch processing must be done while planning and pre-calculating the fixed path. Medial axis transform (MAT) is always used to compute a fixed fly-through path [4]. When the targeted organs consist of several branches, it is always necessary to identify the multiple branches by using interactive segmentation methods [5,6]. A skeleton of the branches can be specified and are refined to get a final path [10]. Sometimes, a small set of center

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points is identified and then linked to a smoothed and centered final path [12]. In this paper, we propose a 3D navigation method in CTVE functions, eliminating the multi-branch problems, and the necessity of planning and pre-calculating a fixed path. With our 3D navigation method, accelerated ray casting is used to render 3D CTVE scenes. By using the compatibility of the 3D navigation method and the ray casting 3D rendering method, the viewpoint direction and location can be tracked in real time while the viewpoint is changing. At the same time it presents and controls the direction and location changes of the viewpoint in x, y, z dimensions. With interactive control of the viewpoint, it can fly in any 3D direction.

MinIP is also a useful visualization function in CT imaging applications. It can be used to visualize abnormal changes in low-density tissues [8,9]. In clinical practice, various pathologies or accidental trauma can cause accumulation of air or gas in the soft tissues (especially in the lung tissues). MinIP can be a suitable method to visualize air or gas pockets in soft tissues. When the conventional MinIP reconstruction method is used, realistic results cannot be achieved when they are rotated in arbitrary directions, because the CT images always contain empty regions surrounding the body tissue regions. The conventional MinIP reconstruction algorithm always chalks up a minimum intensity voxel which relates to the empty margin instead of the tissue regions. To solve such valid voxel searching problems, we presented an automatic correction method to achieve realistic MinIP results in multi-directions.

2. Materials and methods

2.1. Image data acquisition

Two sets of CT image data were acquired:

- The first set was acquired from a chest scanning, locating from the pharynx to the bottom of midriff.
- The second image data set was from a cardiac scanning.

For these two image data sets, the 3D navigated CTVE were used to visualize the trachea and bronchia airways. In the CT images, a beam collimation of 3 mm was used. The table speed was set at 6 mm/s in the spiral scanning acquisition process of a CT scanner. Fifty percent overlapping reconstruction method was used in the image reconstruction to gain an improved volume scanning. The scanning parameters were: 2 mm for image reconstruction increment, 120 kV, 250 MA, standard filter kernel, 32 cm (the chest scanning) and 25 cm (the cardiac scanning) for Field of View (FOV).

2.2. Data field pre-processing

Data field pre-processing involves classification and segmentation approaches, and this process was realized with a pre-specified transfer function. This transfer function was adjustable so as to define the tissue structures which were to be visualized in CTVE.

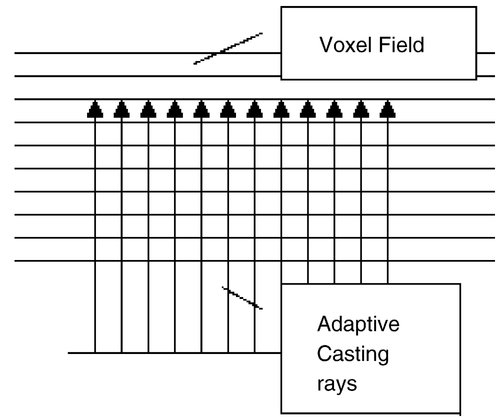

Fig. 1. Self-adaptive ray casting.

2.3. CTVE 3D reconstruction

Direct and accelerated perspective ray casting methods were used to reconstruct and render the CTVE 3D scenes [19,20,21], the accelerated ray casting was effective to avoid empty voxel calculation, and thus to gain fast speed of CTVE rendering. The front to back composition method was used in the ray casting calculation process, which can be described as:

$$I(a, b) = \sum_{i=0}^{n} I_i \prod_{j=0}^{i-1} (1 - \alpha_j)$$

where $I(a, b)$ is the calculated intensity of the resulted image, n the number of the re-sampled points in the casting rays, I_i the intensity at the re-sampling position i and α_j is the opacity at the re-sampled position j which is defined in classification of the pre-processing process. To achieve a real time effect in CTVE flying process, the accelerated self-adaptive ray casting method was used to speed up the 3D reconstruction process, and real time flying was achieved with satisfying reality. The self-adaptive ray casting can be described in Fig. 1.

2.4. 3D navigation methods

The principal purpose of navigation is to pilot the viewpoint to fly inside the targeted organs as freely as possible. In our 3D navigation approach, we divide the navigation environment into five principal elements:

1. Current viewpoint 3D location $\mathbf{X}$.
2. Current viewpoint 3D direction $\mathbf{N}$ (unit vector).
3. Expected direction of turning around $\Delta\mathbf{N}$ (unit vector).
4. Expected extent of turning around a.
5. Expected extent of flying forward or backward b.

The 3D navigation method was used to track the current location and direction of the viewpoint in the flying process. At the same time it presented and controlled the direction and location changes of the viewpoint in x, y, z dimensions. A 3D navigation controller was used to present the expected direction and the extent of forward and backward flying. It also controls the