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Segmentation of Premolar Based on Geodesic Active Region

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Abstract: To find borders between homogeneous regions in the various morphologies, several segmentation resulting from edge-based and region-growing can not produce exactly the same, and a combination of results often work more accurately. Also, clinically usable segmentation for medical imaging requires a high degree of interaction with registration algorithms such as the Insight Toolkit (ITK) and the Visualization Toolkit (VTK). In this paper, we proposed the geodesic active region segmentation to find the inner structure of premolar teeth acquired by micro-computed tomography (micro-CT) scanner. As a result, we discriminated enamel, dentin and pulp zones. Furthermore, we showed that the 3D geometric models of premolar would be useful for the tooth morphology.

1. Introduction

The 3D segmentation and registration of medical imaging methods aimed at visualizing inner dental structures include X-rays, ultrasound, terra-hertz imaging, and computed tomography. Each of these techniques has resolution limitations for accurately reconstructing 3D surface of dental anatomy. However, a comparatively imaging technique, micro-CT, accurately provides the dentin junction of tooth morphology. To find the internal structures of dental anatomy, segmentation and registration is important for surgical planning [1]. A large number of methods are available to segment regions of interest (ROI) from the data which are acquired by the medical equipment [2]-[3]. Tzeng et. al [4] showed the applicability of the cluster-space approach using volume data, in particular higher dimensional volume data and classified into the pulp, boundaries, enamel and dentin boundary, tooth and air boundary, enamel, dentin, and regions of the data set that are not part of the tooth. Kniss et. al [5] showed the several examples for both scalar and more general multivariate datasets. Also, they introduced new interaction modalities and tools to make the process of specifying a high quality transfer function efficient and effective. The research presented here describes 3D reconstruction of the internal morphology of premolar tooth. For the correct junction extraction, we used geodesic active region based on curvature discrimination to control the evolution of the surface. By acquiring a contiguous set of slices, data for a complete volume can be obtained. The fundamental CT data unit is the voxel, which corresponds to the volume bounded by the edges of a pixel and the thickness of the slice image. For implementation of segmentation and visualization, ITK and VTK were used [6]-[7]. The ITK/VTK is the class libraries based on C++. ITK provides the edge segmentation algorithms of 2D or 3D images. Moreover, VTK has powerful visualization capabilities, but only low-level support for interaction like picking methods, rotation, movement and scaling of objects. After acquiring 1000 slices of CT data, we used ITK to find the planar edge of both pulp-dentin and dentin-enamel junction in premolar tooth. Also, VTK is used to visualize the entire internal structure of premolar tooth.

2. Premolar Segmentation

Homogeneity is an important property of regions and is used as the major criterion in region segmentation, whose basic idea is to divide an image into regions of maximum homogeneity. The criteria for homogeneity can be based on gray-level, color, texture, shape, geometric model. Properties chosen to describe regions influence the form, complexity, and amount of prior information in the specific region. The proposed techniques evolve an geodesic active region until a region is detected under the smoothness of homogeneity and the curvature discrimination is embedded into an energy functional that can be related to the initial geodesic region model.

2. 1 Premolar Anatomy

The outer layer of tooth is made of hard crystal. The next layer is softer. The pulp in the middle of the premolar tooth contains nerves that conduct sensations of hot, cold and pain. The visible portion of the tooth is the crown, which is made of enamel. Enamel is the hard outer shell and is able to withstand the stress of biting, chewing and grinding. Dentin is the bone-like substance that makes up most of the tooth. It is found just under the enamel in the crown and under the cementum in the root. At the core of the tooth, beneath the dentin, is the pulp cavity. This space contains the blood vessels, nerves and connective tissue that make up the pulp. The pulp's blood supply provides nutrients that help to keep the tooth alive. The part of the pulp cavity located in the root is called the pulp canal or the root canal. Mandibular premolar located between the canine and molar teeth, largely consists of enamel, dentin and pulp layers, as shown in Figure 1.

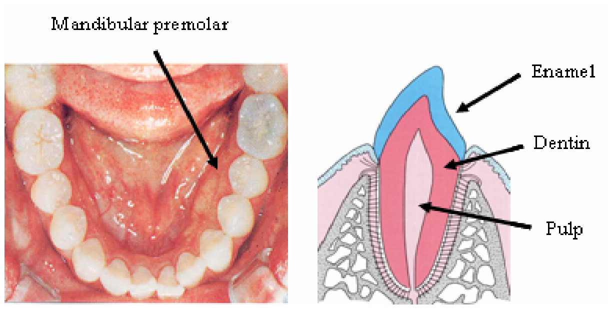


Figure 1. Structure of mandibular premolar

2. 2 Premolar Segmentation

In the several segmentation techniques about the dental CT images, the algorithm based on the interactive construction and modification of data objects are necessary. This includes concepts for interactions with multiple states such as filtering, edge finding and 3D segmentation and moreover a combination algorithm of edge-based and region-growing results in better segmentation.

2. 2. 1 Preprocessing

Prior to region segmentation, the preprocessing steps such as noise reduction filtering techniques are applied. The preprocessing steps consist of the following steps: discrete Gaussian filtering to smooth and minimize the sharp noise, median filtering to correct the scanning artifact of CT scanner.

2. 2. 2 Pulp-dentin Junction

Although the regenerative capacity of the pulp and dentin is not well-understood, reparative dentin is formed as a protective barrier for the pulp. Generally, dentin structure varies with orientation and location and its material comprises the bulk of the tooth mineralized tissues. Its function is to provide elastic support to the overlying hard enamel, enabling the dispersion of mechanical stresses applied during mastication. Dentin is made of tubules of about 0.8–2.5 mm in their inner diameter, filled with the fluid. While soft tissue discrimination was compromised by a low signal-to-noise ratio, the junction between pulp cavity and dentin were well visualized, as shown in Figure 2.

Figure 2. Pulp-dentin junction

In the segmentation of pulp-dentin junction, in contrast to density discrimination, curvature discrimination was much better. Therefore, we used geodesic region discrimination. A geodesic region has a total curvature if and only if for any sequence of normal regions exhausting the geodesic region the total curvatures tend to a common value.

2. 2. 3 Dentin-enamel Junction

The enamel and dentin are bound together at the dentin-enamel junction. It is a hyper-mineralized zone of 30 ㎛ thickness. It has a scalloped outline which makes shallow depressions in the dentin. The projections of the enamel fit into these depression thus providing a better bonding between the dentin and the enamel. Since the region in the dentin-enamel junction has multiple boundaries, dentin-enamel junction was detected by means of isocontour surface technique which is a level set of a continuous function in the 3D space.

3. Experiment

The micro-CT scanner used in this study was SkyScan-1072 which is manufactured by SKYSCAN. In the experiment, approximately 1000 pieces of slice images were obtained from the tooth specimen of 30mm in length, which was secured with a sample holder. The pixel value of each CT slice image was also recorded to compare the locations of peaks representing enamel, dentine, and background noise. Voxel dimensions were kept as close to equal as possible between systems in order to isolate measurement variation due to machine differences rather than voxel size. For the acquired CT images, the attenuation coefficient of 0.266 ~ 0.051 was applied and gray level was 256. The spatial resolution of input image consisted of 1024 x 1024 pixels, the size of which was set to 21.31 ㎛. In case that the tooth length and diameter exceeded 21mm, the axial line of two identical specimens was kept constant and then cross sectional images were obtained twice.

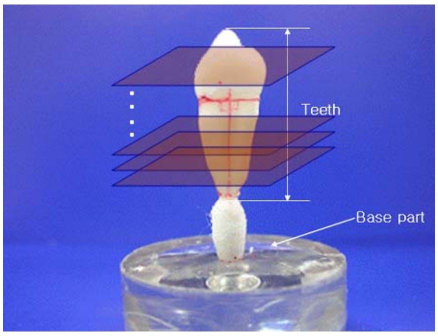


Figure 3. Premolar tooth seed

For segmentation and visualization, ROI images were extracted, as shown in Figure 4. The area of ROI was larger than that of enamel which is the outside boundary of the tooth and the resolution of ROI was 440 x 440.

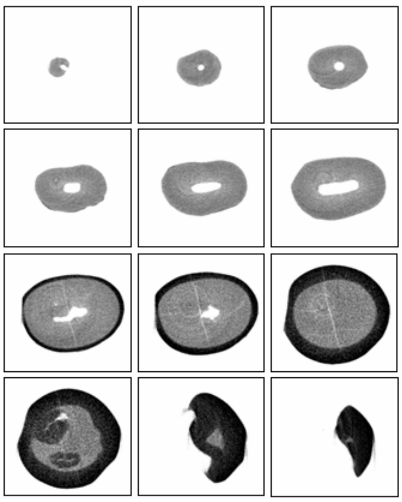


Figure 4. ROI region images of premolar

4. Results

4. 1 Pulp-dentin Processing

Discrete Gaussian filter performs Gaussian blurring by separable convolution of an image and a discrete Gaussian operator. The size of the kernel is extended until there are enough discrete points in Gaussian distribution to ensure that a user-provided maximum error is not exceeded. As shown in Figure 5, Figure 6, the original image was processed by gradient magnitude. After that, the sigmoid filtering was performed to correct the scanning artifact of Micro-CT scanner and geodesic active region was extracted.

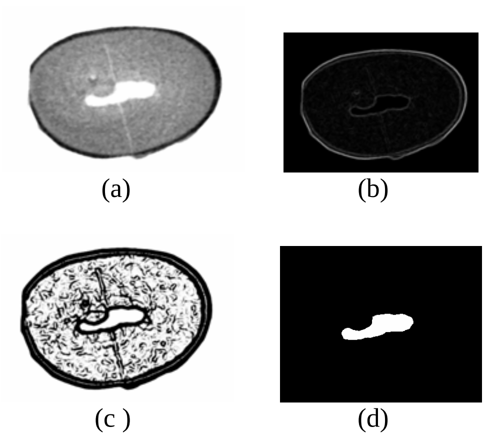


Figure 5. Image of (a) ROI input, (b) gradient magnitude for original image, (c) sigmoid image for (b), and (d) geodesic region of ROI image

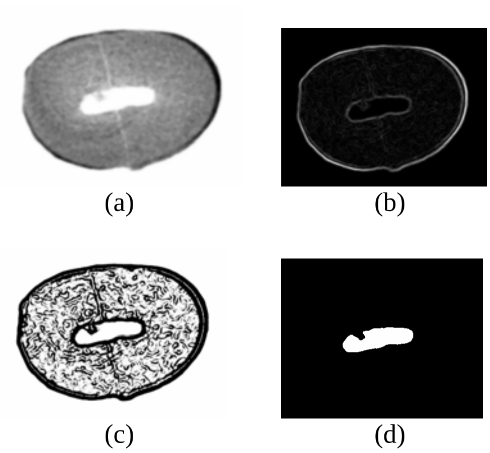


Figure 6. Image of (a) ROI input, (b) gradient magnitude image for original image, (c) sigmoid image for (b), and (d) geodesic region of ROI image

The planar regions of input images has been segmented by setting user defined seed points and using geodesic active contour level sets to get the pulp-dentin junction. Geodesic active contour use minimal distance curves in the image space, in order to decouple the geometric behavior from the parameterization of the contour. The regularization effect in the geodesic active contours is induced by curvature flows that are intrinsic to the contour. In the experiment, the curvature of the contour was 2.0, distance, 5.

4. 2 Dentin-enamel Processing

Isocontour are commonly used to visualize scalar fields. Critical isovalues indicate surface topology changes, merging of surface components or the formation of holes in a surface component. In our experiment, isovalues depend on the outer intensity value of dentin-enamel junction. In Figure 6, isovalues was 60.

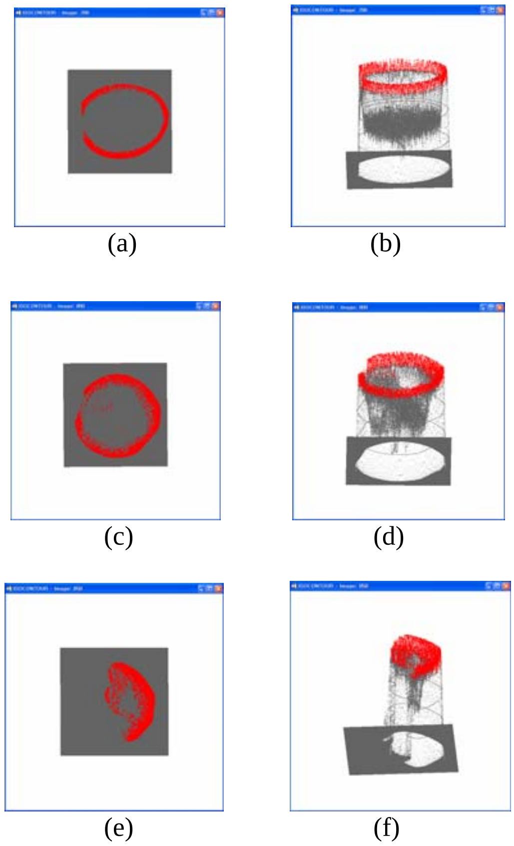
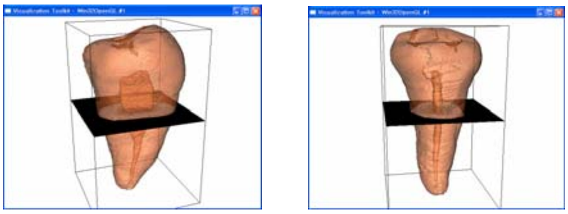


Figure 7. The enamel areas (a), (b), (c) of premolar and their 3D distribution (b), (d), (f).

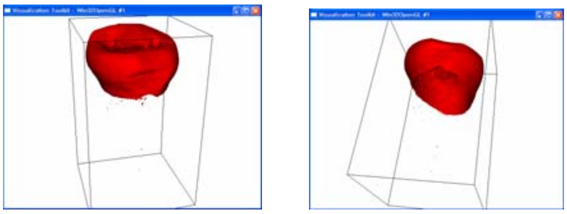
4. 3 3D Visualization

VTK is not an application but rather a cross-platform toolkit that application developers use with other software to create end-user products. VTK presents the developer with sources, filters and graphics mappers that are connected into a visualization pipeline. Data is pulled through the filters by graphical demands that are initiated at the end of the process pipeline. VTK supports a variety of data organizations that range from unstructured data produced by finite element analysis to highly structured data. In the experiments, the dimension of the dataset depends upon the number of input images, was 900. Reading a single file results in 2D slice images, while reading more than one file results in a 3D volume. The spatial image resolution of pulp, dentin and enamel zone consisted of 440 x 440 pixels. Therefore the size of 3D volume was 440 x 440 x 900. In the Figure 8, the front and lateral view of generated 3D volume was shown.



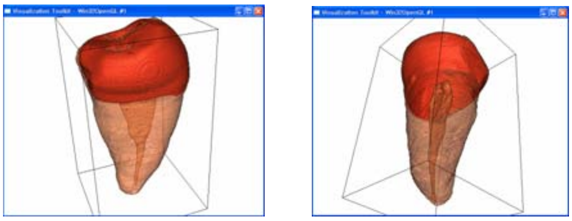
(a) (b)

Figure 8. Visualization of (a) the front view and (b) the lateral view of pulp cavity in premolar image.



(a) (b)

Figure 9. Visualization of (a) the front view and (b) the lateral view of enamel region in premolar image.



(a) (b)

Figure 10. Visualization of (a) the front view and (b) the lateral view of inner structure in premolar image.

5. Conclusion

The segmentation of tomographic image is an important prerequisite for a meaningful visualization in medical morphology. Moreover, the study of segmentation imaging technique for the morphology is to establish quantify the inside volume of the anatomy. Since the robustness of fully automatic procedures is often insufficient, a semi automatic approach was chosen in order to obtain a detailed delineation from CT slice image data. Especially, this study focused on the semi automatic segmentation of dental morphology. In general, micro-CT produces the slice images in which corresponds to the X-ray linear attenuation coefficient, which is primarily a function of density of material. By acquiring a contiguous set of slices, data for a complete volume can be obtained. In this paper, we proposed the geodesic active segmentation about the inner homogeneous areas of premolar slice image, and discriminated the enamel, dentin and pulp zones in premolar tooth. Furthermore, the 3D homogeneous surfaces were visualized to create one kind of view on the data of 3D visualization. Finally, we showed that the surface models of premolar tooth images would be useful for the tooth morphology in dental medicine. Currently, geodesic active algorithm could not perfectly separated the three layers like enamel, dentin and pulp cavity from the obtained CT images since enamel zone has rough boundary and not fully closed. Therefore, our future work will focus on segmentation between dentin and enamel areas.

6. Acknowledgement

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