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Detection of the Root Canal's Centerline from Dental Micro-CT Records

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Abstract— **This paper presents a novel image processing procedure dedicated to the automated detection of the medial axis of the root canal from dental micro CT records. The 3D model of root canal is built up from several hundreds of parallel cross sections, using image enhancement and segmentation, center point detection in the segmented slice, three dimensional inner surface reconstruction and morphological skeleton extraction in three dimensions. The central line of the root canal is interpolated as a 3D spline curve. The proposed procedure can help prepare several kinds of endodontic interventions.**

I. Introduction

ROOT canals differ from individual to individual and from tooth to tooth. That is why whenever an endodontic intervention is planned, the shape of that given root canal needs to be accurately detected. Modern medical imaging devices make it possible to record high resolution cross sections of the teeth, which can be fed to image processing techniques to extract the shape of the root canal. This problem has been solved several different ways, based on recorded data originating from various imaging tools.

Analui *et al* [1] elaborated a geometric approach for modeling and measurement of root canal of human dentition based on stereo digital radiography. Hong *et al* [2] used both 2D radiographic and endoscopic images to build up a 3D tooth model, while Endo *et al* [3] turned to ultrasonic imaging and implemented a fuzzy logic based root canal detection. Lee *et al* [4] used micro CT images and a 3D reconstruction software to measure the three-dimensional canal curvature in maxillary first molars via mathematical modeling.

Recently, several other 3D dental structure reconstruction systems were elaborated, including Willerhausen *et al* [5] who used X-ray images, and Van Soest *et al* [6], who applied optical coherence tomography records for 3D structure reconstruction. Germans *et al* [7] presented an imaging system based on virtual reality that can navigate through the reconstructed 3D structure and make measurements concerning the curvature of the root canal.

For further reading in the topic, the reader is referred to the reviews elaborated by Peters [8] and Dong *et al* [9].

In this paper we introduce a complete image processing procedure, which starts with the enhancement of input micro CT slices, continues with 2D image segmentation based on an enhanced fuzzy c-means clustering [10], identification of the root center in 2D slices via a region growing method. At this point the algorithm can bifurcate: we can interpolate the 3D shape of the root canal's medial axis from the centers detected in 2D, or we can build a 3D tubular shape model and extract the medial axis using 3D morphological operations.

The rest of the paper is structured as follows: section II. describes the proposed image processing procedure, section III exhibits and comments some resulting images, while conclusions are presented in section IV.

II. Methodology

Micro CT records consist of single channel intensity images, representing high-resolution (1500-3000dpi) scans of parallel cross sections of a certain tooth. There are several hundreds of scanned horizontal planes, which are linearly distributed along the vertical axis. In normal cases, cross sections contain a light gray spot (lighter at its edges, with circularly distributed texture due to artifacts), possibly surrounding one or a few darker regions. We need to identify these darker regions and localize their central points in each slice. Afterwards, we need to track the 3D curve that crosses these points and thus approximates the central line. However, there are several difficulties which stem from the following origins:

1. The central line may contain ramifications, which are detectable from the variation of the number of dark regions from slice to slice. However, a bifurcation does not always mean the complete separation of the two dark regions. The accurate spatial position of the ramification is difficult to track under such

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circumstances.

2. Some slices may contain false dark regions, which do not affect the central line. However, these ones usually do not have a corresponding continuation in neighbor slices.
3. Dark regions are not always completely surrounded by the light area. This really affects the detection of the root canal.

The proposed image processing methodology consists of the following steps:

1. Preprocessing for image enhancement requires a simple median filter, which reduces the high frequency noise that is most visible in the texture of the light region. Moreover, a morphological opening and/or closing can be performed, in order to regularize the boundary of the root canal. A further step is establishing the region of interest (ROI) by trimming the image: this way we get rid of the dark areas that represent outer space. It is necessary to store the exact coordinates of the ROI.
2. The segmentation of the slice into dark and light regions is performed by a quick, histogram based fuzzy c-means clustering [10]. There are two strategies that have been developed for this purpose. The simpler strategy sets the number of classes to two, and thus we obtain a binary segmented image. This approach is extremely quick, but sometimes fails because of the artifacts that occur quite frequently. This is why a two-stage clustering technique was developed. According to this evolved approach, in the first stage the clustering produces four classes of pixels. In the second stage it is decided, whether one or two of the darker shades will belong to the dark areas, based on the differences of the cluster prototype colors. Finally we obtain a binary image, where the darker regions have to be tracked.
3. The identification of dark spots situated within the light area of the binary image, is performed by an iterative region growing method. As long as there are dark pixels in the segmented image, a dark pixel is chosen and a region is grown around it. Outer space (which is also dark) is obviously discarded, and the detected dark spots are separately stored. There are some cases, when a single canal is manifested by more than one dark region. To detect such cases, an artificial neural network (ANN) was trained, which decides the number of centers to be detected from the number of dark regions and their relative positions.
4. Central point localization takes into consideration a few features: as a first approximation, the dark region's center of gravity is considered central point. This first decision has to be overruled or adjusted whenever:
   a. the first approximation resides outside or too close from the edges of the dark region;
   b. the shape of the dark region is odd (possibly two or more dark regions are unified);
   c. the dark region is connected with outer dark areas, that is, it's not completely surrounded by the light area;
   d. adjacent slices from the micro CT record have to correlate: there cannot be a relevant change in the structure found within neighbor slices. Whenever a relevant difference is obtained, there are two possible choices: either we find the cause of the difference, or we can even afford to discard the "outlier" slice, as the missing information won't affect too much the approximation of the 3D medial axis.
5. The central line is constructed upon the detected central points, and is modeled as a spline curve in three dimensions.
6. A better approximation of the root canal's central axis can be achieved with a 3D skeleton detection method. In this order we need to reconstruct the 3D boundary of the root canal, which will look like a curved and deformed tube with possible bifurcations [11, 12]. The obtained tube is then skeletonized using 3D morphology.
7. Further on, from the segmented slices, we can extract the outer surface of the light region and reconstruct a tubular surface model of the whole tooth, which after a triangulation, can be interactively visualized using 3D computer graphics.

The algorithm of central point and line localization is implemented as a binary decision tree, most of whose decisions are made automatically. However, in some odd cases, when several centrally located dark spots are found within a single slice and adjacent slices cannot clarify the case, it is necessary to help the algorithm at some decisions. In this case, some interaction is required to accomplish the image processing. All other processing steps are performed automatically.

III. Results and Discussion

The proposed algorithm can automatically process more than 95% of the recorded image sets, while the rest of the cases need manual interaction. Using a Pentium4 PC, the processing of a slice in 2D lasts 0.3-0.5 seconds, while a central canal reconstruction is interpolated in less than a second. The accuracy of the detected medial axis also depends on the number of slices involved. An accuracy that is suitable to guide medical intervention can be obtained from carefully selected subsets of at least 20 slices.

Figure 1 exhibits the intermediary results provided by the 2D segmentation. Three cases of various difficulties are presented in the three rows of the image.

The first row presents a simple case involving a slice with two dark spots representing two different, easily detectable root canals (there was a bifurcation several slices away from this one). The slice in the middle row manifests an odd shaped dark region, which was successfully detected.

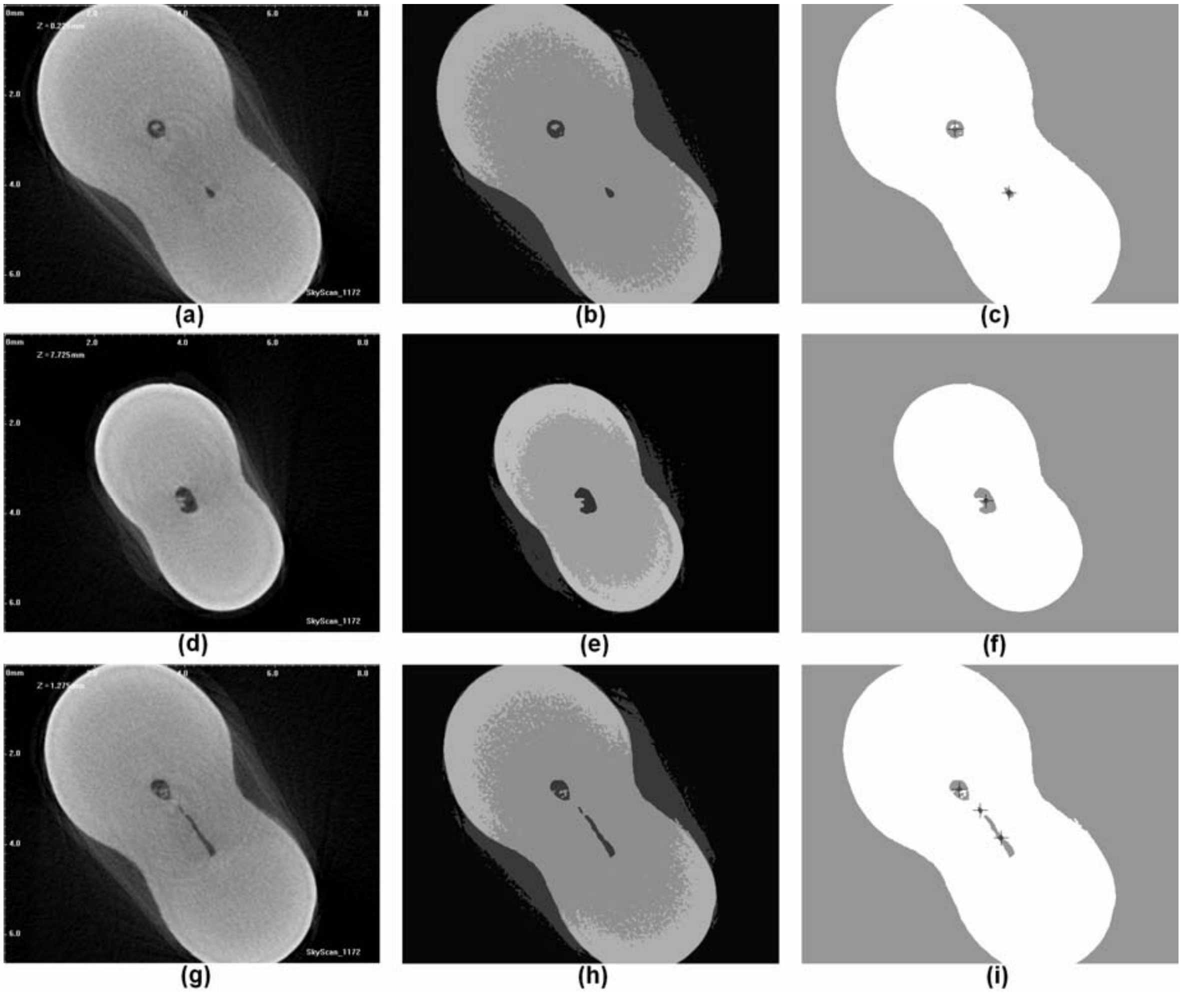

Fig. 1. Detailed view of image segmentation in 2D: each row represents a different slice. First column shows the original recorded images; second column presents the clustered images (4 clusters); last column indicates the segmented binary images with detected center points

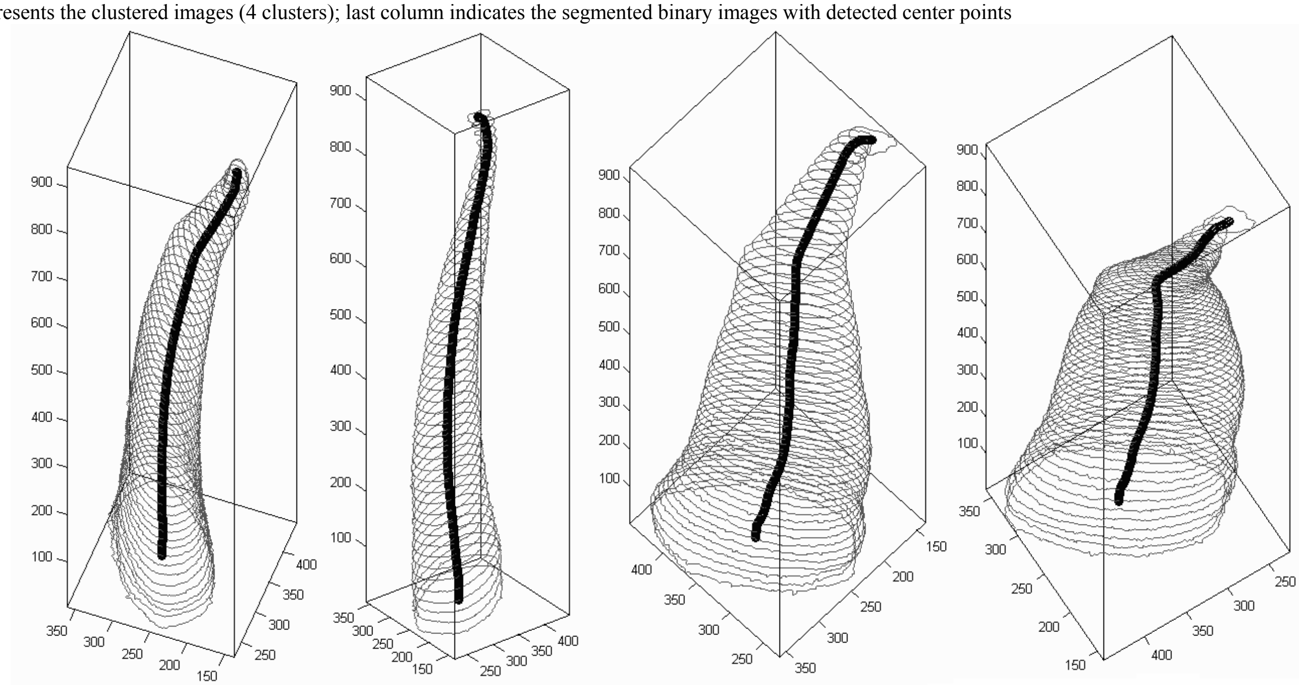

Fig. 2. 3D views of a root canal, with the extracted medial line. Numbers indicate pixels, which are easily convertible to millimeters

The slice presented in the third row shows a difficult case: three different dark spots are present in the segmented images, but they belong to only two different canal ramifications. This is the case which requires correlation test with neighbors or decision overruling performed by the ANN.

Figure 2 shows four different 3D views of a root canal, together with its detected medial axis. The central line was produced from 944 equidistant slices, segmented in 2D with binary separation using the global optimal threshold.

I. Conclusions

We have proposed and implemented a complex image processing procedure for the detection of the center line from dental micro CT records. In most cases the algorithm performs automatically, but there are still a few nodes in the decision tree where the decision has to be made interactively. Thus we have created an imaging system that can efficiently assist certain medical interventions.

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