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Tooth Segmentation in Dentistry: A Review

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ABSTRACT

The emergence of artificial intelligence (AI) has marked the past decade as a breakthrough in the advancement of technology. Every industry has embraced AI with great excitement and the field of dental science is no different. Artificial intelligence has several uses in dental and medical science, ranging from fundamental process of gathering a patient's medical history, using machine learning algorithms to predict dental caries and finally for data processing to extracting the information from the data for diagnosis. This paper reviews the role of tooth segmentation in dentistry.

Keywords: Artificial Intelligence, Deep Learning Method, Tooth Segmentation, Watershed, U Net

IMAGE SEGMENTATION

It is a technique which is commonly used in digital image processing and analysis to partition an image into multiple parts or regions. Oftenly it is based on the characteristics of the pixels in the image.

TEETH SEGMENTATION

In computer-aided procedures and clinical diagnosis, teeth segmentation plays an important role. It can produce approximate outlines of doubtful regions to provide features which enables distinction between tooth and other tissues.[1]

PURPOSE OF TOOTH SEGMENTATION

The question arises that why do we need image segmentation when we have imaging modalities such as CBCT and CT?

- The purpose of image segmentation is to segment the image at the pixel level to get segmentation mask for each tooth.[2]
- Due to the presence of complex and intricate anatomic structures, which make extraction of boundaries difficult.[2]Additionally also due to presence of noise, artifacts and low contrast present on the diagnostic image obtained.[2]
- Automatic segmentation of individual tooth is useful for computer-aided analysis towards clinical decision support and treatment planning.[2]
- Three-dimensional reconstruction of individual tooth after the segmentation also plays an important role in simulation.[2]

Armamentarium

For image segmentation we require the following armamentarium are required:

- An imaging modality such as CT/CBCT/OPG or IOPA
- Software such as itk-SNAP, BlueSkyBio DIGITAL, 3DIEMME, MONAI to carry out the segmentation process

CLASSIFICATION

Depending upon the amount of user interaction, methods of tooth segmentation

can be divided into manual, semi-automatic and automatic segmentation.

MANUAL SEGMENTATION

The most general approach to tooth segmentation is the manual method. Manual segmentation methods require users to draw strokes or click along the potential cut boundary. The results of manual segmentation methods are precise, as it involves comprehensively labeling the three-dimensional (3D) structure in each two-dimensional (2D) slice.[3]

METHOD

Manual segmentation requires the operator to manually trace or outline the region of interest using a tool such as a mouse or stylus. After which, the axis of the individual teeth are corrected and segmentation model generated. The segmentation model can be used to visualise the patient's dental anatomy, accurately assess the position, size, shape of individual teeth, arch alignment and calculate inter arch distances and visualise various tooth movements which can help clinicians formulate an appropriate treatment plan.

LIMITATIONS OF MANUAL SEGMENTATION

- It is time consuming process.
- It can be prone to fatigue and errors, particularly when the operator is required to perform repetitive tasks over an extended period. This can lead to inaccuracies and inconsistencies in the segmentation results which can introduce inter- and intra-operator variability and low reproducibility.[4]

SEMI-AUTOMATIC SEGMENTATION

It is the process whereby automatic segmentation is followed by manual checking and editing of the segment boundaries.

METHODS

Semiautomatic segmentation requires the operator to manually initialization of the model after which automated boundary detection done by the software which is then preceded by manual correction and iterative refinement of the segmented boundaries then final segmentation result is obtained after multiple repetitions of automated and manual refinement.

COMMONLY USED SEMI AUTOMATIC SEGMENTATION TECHNIQUES

WATERSHED METHOD

Watershed segmentation is a technique used in image processing and computer vision to segment objects or regions of interest in an image based on the concept of watersheds. In this method operator required image slice that contains all teeth. Next step is image enhancement without image enhancement, watershed algorithm cannot separate teeth regions correctly because there may be voids or holes in the image and image filling in gray intensity is used for filling these regions. Finally the enhanced image is fed into the watershed algorithm to obtain the desired results.5 It's important to note that the success of watershed segmentation in dental images, as in any image segmentation task, depends on the quality of the input image, the choice of preprocessing techniques, and the accuracy of marker placement.

SEED PIXELS (REGION GROWING)

It is a method that involves selecting seed points or regions of interest within the image and then growing these regions by adding adjacent pixels that meet certain criteria, such as similarity in color or intensity values.6 It's often used in medical imaging for tasks like tumor segmentation, where a radiologist may manually select seed points within a tumor region to initiate the segmentation process.

CLUSTER BASED SEGMENTATION

Cluster segmentation is a technique used to segment an image into regions or clusters based on similarities between pixels or groups of pixels. It is able to detect small

variations in intensity value and also combinations of any grouping criteria can be used.[7] Cluster-based tooth segmentation methods can use various clustering algorithms, such as K-means, Fuzzy C-means, or hierarchical clustering. The choice of clustering algorithm and feature extraction techniques may vary depending on the specific dental image dataset and the complexity of the problem.

AUTOMATIC TOOTH SEGMENTATION

Automatic segmentation refers to the process whereby segment boundaries are assigned automatically by a program does not rely on user interaction. This approach has an edge because once the method has been constructed, the segmentations can be performed relatively quickly.

Automatic segmentation can be divided into:

1. Semantic segmentation

Semantic segmentation assigns a specific label or category to each individual pixel within an image. Its primary purpose is to identify and differentiate groups of pixels that represent separate and meaningful object categories. Semantic segmentation task focuses on differences between categories. It is used to separate the teeth, jaws and background, without distinguishing between individuals in each category ("Tooth" or "Jaw)."

2. INSTANCE SEGMENTATION

Instance segmentation is a fusion of semantic segmentation and object detection, where object detection is done by identifying all instances of a particular category within an image. Instance segmentation goes beyond standard segmentation by not only segmenting objects but also distinguishing individual instances of the same object class within the segmentation task. Instance segmentation task focuses on differences between individuals within a category. Both the category label and the instance label (within the class) are required; that is, the individuals in each category ("Tooth" or "Jaw)" must be distinguished.

Segmentation approaches have been broadly classified into seven categories.[8]

1. STATISTICAL SHAPE MODEL BASED

Statistical Shape Models (SSMs) represent a valuable mathematical tool and is currently very popular in the Oral and Maxillofacial Surgery where patient-specific devices or surgical procedures is based on an interactive design approach. In this three-dimensional model of the maxilla/mandible external geometry have been reconstructed from CT scans following a common procedure for segmentation and post-processing. The Segmentation process involves first segmenting the whole skull after that segmenting maxilla/mandible with teeth geometry and then maxilla/mandible without teeth, finally the soft tissue geometry is reconstructed.[9] Using a probabilistic shape representation, a statistical shape model is constructed that integrates into the graph cut framework.

2. ACTIVE SHAPE MODEL

Active shape models (ASMs) are statistical models of the shape of objects which iteratively deform to fit to an example of the object in a new image. It is a statistical shape model that uses a set of training images to learn the shape and appearance of an object of interest. In order to be able to compare training shapes, it is important that the shapes are represented in the same coordinate frame. Therefore, the shapes have to be aligned with respect to a set of axes, in order to remove any kind of variation.[10] ASM works by alternating between two steps, first is the generation of a suggested shape by looking in the image around each point for a better position for the point. This is commonly done using what is called a "profile model", which looks for strong edges. Second step is confirming the suggested shape to the point

distribution mode, commonly referred to as "shape model".

3. ACTIVE APPEARANCE MODEL

It is an extension of statistical shape model and active shape model to further statistically model the texture information of the object. For example, one of the objectives was to determine if the quantity and quality of bone is sufficient to sustain an implant while avoiding critical anatomic structures. An automated system based on active appearance model is proposed to segment the cortical bone, trabecular core and the mandibular canal containing the dental nerve. The given data set is annotated using a set of landmarks and the segmentation process is carried out.[11]

4. ATLAS BASED METHOD

Atlas-based segmentation exploits knowledge from previously labeled training images to segment the target image. An atlas consists of a patient model with pre segmented anatomical structures registered on the current patient scan. It utilizes approaches to register a known reference segmentation mask (that forms an atlas) to a patient. The key advantage of atlas-based segmentation compared to other segmentation techniques lies in its capability to effectively segment an image even when there is no clearly defined relationship between regions and the intensity of pixels. This situation typically arises when objects sharing a similar structure, such as texture, need to be segmented. Here, a 3D surface model is acquired from a threshold segmentation process.8

5. LEVEL SET METHOD

The 3D level set method theoretically an alternative solution for the branching root segmentation in contrast with 2D methods. The concept of the level set method is to enclose a curve within a surface. It requires an initial contour curve and then, the segmentation is followed. This method is effective for the segmentation of tooth as well as the human jaw from CT images. The segmented contours can be used for 3D visualization and individual manipulation of the tooth models.[8]

6. CLASSICAL MACHINE LEARNING METHODS

In the past few decades, the role of machine learning in medical applications has greatly increased. In the field of ML, mathematical models are employed to enable computers to learn inherent structures in data and to use the learned understanding for predicting on new, unseen data.[8]

7. DEEP LEARNING BASED METHODS

In recent years, deep learning-based segmentation algorithms have become popular among researchers. They have shown a tremendous performance in the area of image segmentation and provide more flexibility and powerful capabilities than the traditional machine learning methods and require less expert analysis.[8]

COMMON DEEP LEARNING BASED SEGMENTATION METHODS

U – NET

U-Net was one of the most influential segmentation models dedicated to biomedical fields. The U-shaped network consisted of symmetric compression paths and expansion paths and elastic deformation networks.

Extracting any single tooth from an original CBCT scan is very difficult, since the varied shape and complex distribution of teeth. Using original CBCT sequence, operators first get the dental arch curve by several steps. Then, operator project along the tangent of each point on the dental arch curve to generate a panoramic view of the teeth sequence. The panoramic image will be put into the algorithm to identify the type of each tooth and to get the bounding rectangle of it.[12]

T SEGNET

It is a two-stage neural network in which firstly detects all the teeth and then segments each detected tooth accurately.

TSegNet is a novel end-to-end learning-based method for automatic tooth segmentation. Instead of utilizing bounding box, it exploits the centroid (i.e., the center of mass) of a tooth. The most stable feature point inside any tooth shape is centroid point. This point is not influenced by tooth shape, position and orientation. The workflow consists of two-stage network architecture and algorithm pipeline. First the dental mesh is fed into the centroid prediction network in stage one then the cropped features go through the tooth segmentation network in stage two. Finally, we derive the accurately segmented tooth objects.[8]

TOOTH NET

Method is fully automatic without any user annotation and post-processing step. It produces superior results by exploiting the novel learned edge map, similarity matrix and the spatial relations between different teeth. It is two-stage network architecture for tooth instance segmentation and identification.[8] In the first stage, we extract the edge map from CBCT images by a deep supervised network. In the second stage, it superimposes the learned edge map features with the original image features.

CONCLUSION

Tooth segmentation is a useful tool for diagnosis, decision-making, treatment planning and prediction of treatment outcomes more accurately and efficiently, thus reducing dentists' workload.

Declaration by Authors

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