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Tooth/Teeth Segmentation and modeling from X-ray/CT images: A Survey

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ABSTRACT

Segmentation of tooth/teeth from dental computed tomography (CT) or X-ray images and thereby its 3D visualization is of great significance for computed assistance strategies such as anomalies detection, planning for orthodontics, dental implants, face and jaw surgeries and much more. This application is often used in forensic science for human identification using matching of post-mortem (PM) and antemortem (AM) dental scans, lesions detection and few others. Some of these applications require isolation of tooth and thereby its critical examination using 3D visualization. The aim of this paper is to discuss various approaches proposed so far by different researchers for segmentation and modeling of the tooth from CT images. It also discusses various challenges in the field of orthodontics and different ways to overcome them.

***Index Terms*:** segmentation, Dental CT images, X–ray images, 3D Visualization

1. INTRODUCTION

In recent years, with the development of medical imaging in the field of orthodontics, a perception of human body parts such as bones and teeth has been used for Computer-aided diagnosis (CAD) systems. It has gained great significance for various orthodontics applications such as abnormalities detection, dental implants, surgical planning, forensics and much more. CT images and X-ray images provide appropriate imaging modalities for extraction of internal features. The purpose of extraction or segmentation is an acquisition of the desired object of interest for further analysis. On the other hand X-ray images have been commonly used by dentists to isolate lesions and monitor the development of periodontal defect that is difficult to diagnose with the naked eye. For the segmentation of teeth from these dental images, different techniques are used based on the requirements of the application and imaging modality used. Dental images are broadly classified into two types i.e. intraoral and extraoral. In case of the intraoral, X-rays film are placed inside the mouth whereas in a case of the extraoral, X-ray film are placed outside the mouth [1]. Intraoral are either bite-wing x-rays in which the details of both lower and upper teeth are reflected in one scan or the periapical x-rays which reflect the whole tooth from crown to beyond root. It is recommended to identify any unusual variations in root and surrounding tissues. Figure 1 shows different samples of intraoral x-rays.

On the other side, Extraoral is mostly used for dental problems in the jaw and skull [1]. Extraoral comprises of panoramic x-rays, Dental computed tomography (CT) or MRI imaging. Panoramic x-rays show the entire area of the mouth including both upper jaw and lower jaw in a single scan. It detects the position of both emerging as well as emerged teeth to visualize impacted teeth and diagnose the tumour. Dental computed tomography (CT) is an imaging technique that looks at the interior structure in three dimensions. This is recommended to finds problem in bones such as cysts, tumour or fractures. MRI imaging is an imaging technique that considers the 3D view of the oral cavity including teeth and jaw. It is recommended for the evaluation of soft tissues.[1] Figure 2 shows different types of extraoral x-rays.

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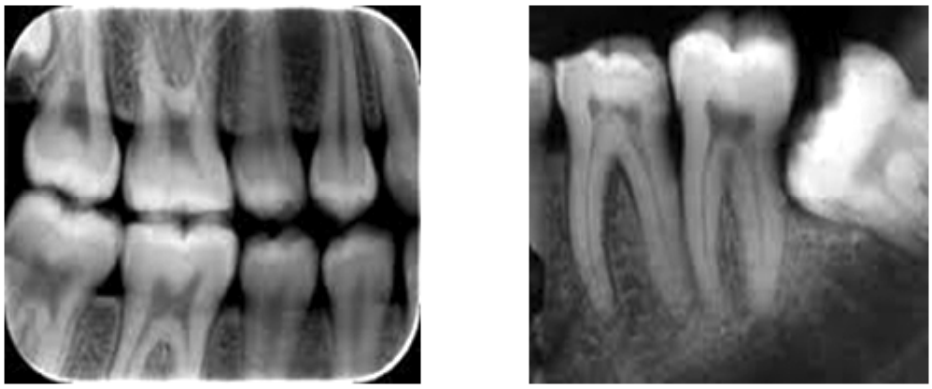
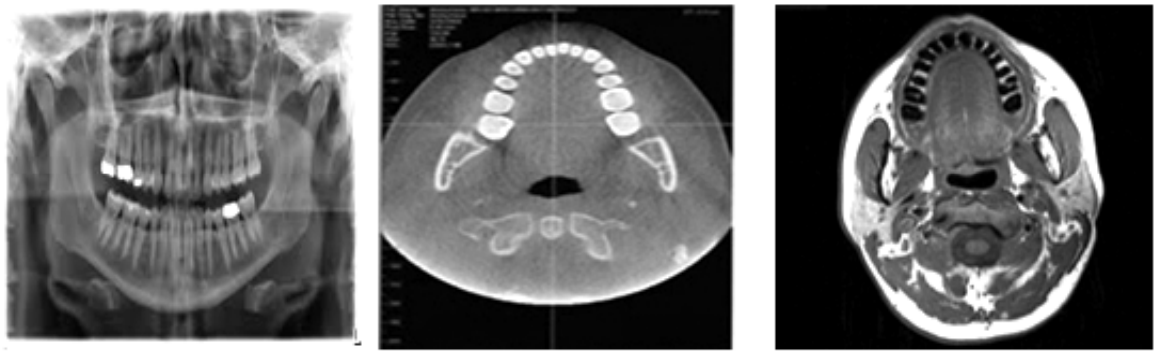


(a) (b)

Figure 1: (a) Bite-wing x-rays (b) Periapical x-rays [1]



(a) (b) (c)

Figure 2: (a) Panoramic x-rays (b) Dental computed tomography (CT) (c) MRI imaging [1]

The survey given below illustrates various techniques used by different researchers over the world from time to time for segmentation and classification of the tooth.

2. LITERATURE REVIEW

The work done till date for the extraction of tooth/teeth from CT/X-Ray images is as follows.

Jain et al. in 2005 proposed an approach that used Hidden Markov model (HMM) for Registration of dental atlas from Radiographs. They used a fusion of Support vector machine (SVM) with other methods for classification of teeth. Dental radiographs before and after death were used for identification of human. Classification of upper teeth was found to be more difficult than lower teeth due to its complex anatomy. But it had a drawback of short sequences error in registration and detection of missing teeth. [2]

Zhou et al. in 2005 presented a segmentation approach for identification of human based on content-based retrieval from post-mortem (PM) i.e. after death and antemortem (AM) i.e. before death dental images. It has an important role in the field of forensics. They used active contours “Snakes” for ROI localization and image enhancement for segmentation followed by region growing to obtain dark areas around missing tooth or air gaps and finally applied adaptive thresholding to isolate teeth contours. This process involves two main stages of archiving and retrieving. In archiving processes, AM images are segmented to achieve contour and store them in the database. Whereas in a retrieving process, PM image was submitted to segment and extract a contour of teeth for matching them by calculating Hausdorff shape distance between them. Finally, Bayes classifier was used for the purpose of classification. [3]

Gao et al. in 2008 proposed a segmentation approach for touching tooth followed by construction and visualization of an individual tooth from CT image sequences. Segmentation of crown was considered

more challenging due to touching boundaries of the tooth. For the extraction of true and false outer boundaries, they used the typical direction of emerging contour and a gradient direction of an image. Whereas, for the segmentation of tooth root they used single level set and for the segmentation of tooth crown they used coupled level set followed by a principle of region competition to avoid overlapping of contours. The contours of preceding images were used as an initial contour for next slice. Finally, inverse gradient removal was used to remove inner edges and prevent outer boundaries. This approach has improved performance as compared to previously existing approaches. [4]

Hosntalab et al. in 2008 proposed a segmentation approach for teeth. They used ostu thresholding for extraction of head mask, level set function for classification of bony tissues and teeth from non-bony regions. For initial segmentation, panoramic projection images were divided into segments such that each segment has one tooth only and finally applied variational level approach for segmentation followed by butterworth filter for reduction of noise and other artifacts. 3D visualization was carried out by using MEDAL software. This approach was better than others in performance but can be further improved for automation. [5]

Akhoondali et al. in 2009 initially used a 3D median filter to remove salt and pepper noise from the dental scan. Then to separate mandible and maxilla, maximum intensity projection (MIP) is used in y direction followed by maximum intensity projection in the z direction. Region growing method was then used to segment root in three steps with four threshold values. 1st Threshold to locate seed points, 2nd Threshold as stopping threshold, 3rd Threshold for smoothing and reducing noise using the mean filter and finally 4th Threshold to remove non-bone tissues. After this, volume rendering was used for visualization by extracting iso-surfaces and weight masked image from threshold filter was used to generate a secondary mask for reduction of metal artifacts. This approach proved to be better than level set techniques but had a drawback of increasing none-tooth bones due metal artifacts. This approach segmented and classified images effectively and proved to be a good tool for identification of human but, needs a little improvement in the proper matching of AM and PM images by extracting teeth with increased accuracy.[6]

Gao et al. in 2010 proposed a segmentation approach for the tooth from CT image sequences using energy function with shape and intensity prior information with the use of the level set approach. They used single level set approach for root segmentation and coupled level set for crown segmentation. Information of gradient direction was then incorporated into level set to avoid catching of surrounding boundaries. This approach has overcome the drawback of previously existing approaches by improving the segmentation accuracy of the tooth and can also be improved by taking common tooth boundaries, topological changes of a tooth and noisy CT image into consideration. [7]

Lin et al. in 2012 proposed an approach for segmentation of lesions from dental X-ray images. These images had a drawback of poor image quality, an intricate topology of lesion regions, erratic orientations of teeth and depletion of clear boundaries between normal teeth and gums. Lesion detection from gums involves two stages i.e. “Removal of Teeth parts” and “labeling and localization of lesion regions”. Initially, an average filter was applied to denoise the image followed by morphological dilation and histogram equalization for contrast stretching. They then used canny edge detector and ostu thresholding for detection of contour. Finally, the centre point of each connected component and a closing operation was used for extraction and removal of teeth parts for detection of lesions from gums. This approach has improved the robustness to illumination variation as compared to existing approaches. [8]

Lin et al. in 2013 proposed an approach for separation of lower and upper jaw followed by isolation of single tooth. Bottom red hat transform was used for enhancement of the image. Extractions of jaws were carried out using integral projection of each vertical line, founding of desired gap valley using an angle variation of an image and strip windowing scheme for obtaining horizontal line. Whereas, for the isolation of single tooth, adaptive windowing scheme is used. This approach also worked well for teeth with severe occlusion and uneven illumination. [9]

Lin et al. in 2014 proposed a segmentation approach for isolation of teeth from radiographs positioned on analysis of local singularity. This approach worked in four stages i.e. enhancement of image using adaptive and transformations of a global power law, analysis of local singularity using Holder exponent (α) for texture analysis, tooth isolation using analysis of connected component and Otsu's thresholding and delineation of the tooth using boundary tracking by snakes and morphological operations. This approach was able to correctly segment teeth which have undergone root canal treatment but needs improvement in isolation of broken teeth. [10]

Dong et al. in 2014 proposed a coupled level set method for segmentation of teeth from CT images. They initially used normalization and rotational symmetric Gaussian filter for pre-processing of CT images to reduce noise. Different energy terms were used for evolution of contours such as penalizing energy to penalize contour using Signed distance function. Region energy to separate the regions into object and background regions. Edge energy to force the contour to approach to the edges in the image. Shape prior energy to evolve contour to approach the final segmentation. Finally, they used dentine wall thickness to shrink thin regions. This approach has prevented the shrinkage and leakage problem of the tooth but had a drawback in the extraction of a tooth when shape changes with multiple branches.[11]

Yanagisawa et al. in 2014 proposed a reconstruction approach for the shaping of teeth from CT images by extracting its 3D shape and then applied morphological processing for elimination of discontinuous points. Firstly, they included pre-processing which involved normalization of bright values based on slice energy (SE) and filtering by using the bilateral filter. Secondly, they included region extraction where each small square was represented by voxels and areas surrounded by thick lines for applying region growing approach which initiated with a selection of seed points. This approach has been analyzed to remove noise and to extract discontinuous points by suppressing the surrounding tissues. But had a drawback that a thin layer of the unextracted region remained on the surface of the enamel of extracted tooth. [12]

Kang et al. in 2015 proposed an approach that used seeded region growing for segmentation of teeth from CT images. This approach was able to distinguish socket from teeth which are considered a challenge as a difference between them is difficult to analyze. A threshold value was used to classify teeth and socket for accurate segmentation of teeth and median filtering was used to reduce the noise. Repetition of an algorithm for slices was decided on the basis of over segmentation or under-segmentation results of the size of the region. [13]

Jung et al. in 2015 proposed an approach that combined both CT images and optical scan data for modeling of a tooth. Graph cut segmentation method was used for co-segmentation between CT and optical scan. For the extraction of teeth from CT images, optimal global thresholding was used to separate hard bone from jaw bone and seeded region growing was applied for extraction of the tooth from teeth. On the other hand from optical images feature points were selected to match with features extracted from CT images using marching triangulation method and advancing front method. Finally, registration of image was done using Iterative closet point algorithm and the proposed approach has improved the problem of metal artifacts as compared with previously existing approaches. But its robustness still needs improvement by testing it in a large number of datasets. [14]

Mortaheb et al. in 2016 gave another approach comprising of steps such as Metal artifacts and noise removal, Initial segmentation and individual tooth region detection followed by final segmentation and 3D visualization. They used fuzzy C-mean clustering based thresholding and least square support vector machine (LS-SVM) for classification followed by application of guided filter to reconstruct slice, smoothen it and preserve edges. Mean shift filter was then applied to smoothen the slice and arc were fitted for estimating separation lines using least square spline modeling by dilating the binary image of previous step using morphological operations. Mean shift algorithm was then finally applied to segment CT images and shear wrap approach was used for 3D visualization and volume rendering of a segmented image. [15]

Table 1 shows the performance of above discussed images with the details of datasets used.

Table 1
Comparison of existing approaches

Author's/Year	*Approach Used*	*Datasets Used*	*Performance*
Jain et.al [2] 2005	Hidden Markov model, Support vector machine	562 Tooth sequences, 25 Subjects	90% classification accuracy and 88% registration accuracy
Zhou et.al [3] 2005	Active contours, Region growing, Bayes classifier	60 training images and 123 testing images	Error rate of 4% and precision of 95%.
Hosntalab et.al [5] 2008	Variational level set approach, Butterworth filter	30 Multislice CT consisting 3600 images	98.7% and 94.9% accuracy for incisor and canine.
Akhoondali et.al [6] 2009	Median filter, Maximum intensity projection, Region growing	39-112 slices with thickness of 0.6 to 0.8	Average relative overlapping of 86% and accuracy of 97%.
Gao et.al [7] 2010	Level set approach	18 dental CT images	Subjective analysis by visualization
Lin et.al [9] 2013	Bottom red hat transform, adaptive windowing scheme	60 bitewing images with 252 teeth	Accuracy of 98.71% for lower teeth and 95.63% for upper teeth.
Lin et.al [10] 2014	Otsu's thresholding, Morphological operations	28 dental radiographs with 160 isolatable teeth	Accuracy of 89% and Standard deviation of 0.07
Dong et.al [11] 2014	Level set method, Active contour approach	45 teeth from 10 patients with 30 incisors and 15 canines.	0.964±0.11 Jaccard index and 0.981 ± 0.008 Dice index
Yanagisawa et.al [12] 2014	Morphological processing, Bilateral filter	Not Specified	Precision of 0.943, Recall of 0.843 and F-Measure of 0.890
Kang et.al [13] 2015	Seeded region growing, median filtering	CT Scans of 10 people with 14 individual teeth.	Average error volume of 2.29 ± 0.56%
Mortaheb et.al [15] 2016	Fuzzy C-mean clustering based thresholding, Least square support vector machine (LS-SVM), Mean shift filter, shear wrap approach.	14 CBCT images.	Sensitivity 83.24% Specificity 98.35% Precision 72.77% Accuracy 97.62%

3. DISCUSSIONS

Among dental images, CT images are prevalent for 3D (three dimensional) visualization of the teeth. But, dental CT images face major challenges in segmentation due to the special temperament of tooth structure and other properties of this type of images:

- The tooth does not have an intangible boundary due to which it has many cartographic changes with some holes in the tooth which facades to appearing of inner edges that make segmentation more troublesome.
- Adjacent teeth are often in touch and finding the common boundary between them is one of the segmentation difficulties.
- Tissues around the teeth such as enclosing jaw bones and periodontium lead to many artificial boundaries around the actual border of teeth.
- The tooth clefts into several branches in regions of a root, hence finding the right boundary of each root is another difficulty of the same.
- CT images are often noisy and must be enhanced before segmentation.
- CT images usually have more than 100 slices contain the teeth hence, an efficient algorithm is required for fast segmentation.

Most of the existing methods for segmentation of dental CT images are semi-automatic which require expert user interaction.

4. CONCLUSION

This study presents various approaches used for segmentation and modeling of the tooth from X-ray and CT images. These approaches have their specific significance depending upon type of images, environment conditions and variety of applications. Survey carried out for segmentation and modeling of the tooth is of great significance due its wide range of application such as anomalies (lesion) detection, dental implants and orthodontics planning including surgeries. Challenges such as noisy CT images, complex tooth anatomy and improper boundaries between adjacent tooth and metal artifacts have been discussed. Also, different pre-processing approaches such as image enhancement and smoothing for making the CT images appropriates for segmentation and classification are discussed.

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