Teeth Segmentation of Bitewing X-Ray Images Using Wavelet Transform

Sina Salimzadeh
Department of Electrical & Electronics Engineering, Girne American University
Karaoglanoglu, Kyrenia, Mersin10, Turkey
E-mail: sina.salimzadeh@gmail.com

Sara Kandulu (Izadpanahi)
Faculty of Engineering Technopark Building, Girne American University
University Drive, Karmi Campus, Karaoglanoglu, Mersin10, Turkey
E-mail: sarakandulu@gau.edu.tr

Keywords: teeth segmentation, bitewing X-ray images, dental radiographs enhancement, wavelet transform, morphological operations

Received: May 12, 2019

Within the recent twenty years, the dental X-ray images have widely been employed in forensic odontology for human identification, particularly where mass disasters happen. In this paper, a novel method is proposed for the process of teeth segmentation and individual teeth isolation of Bitewing X-ray radiographs. The main objective of this study is to develop an automatic teeth segmentation approach that can be used in an Automated Dental Identification System (ADIS).
The proposed method is based on separating teeth according to edge lines between crowns of teeth. It comprises four phases as image enhancement, edge detection by using wavelet transform, Region of Interest (ROI) definition, and morphological processing. Image enhancement in our case is done by image sharpening using a Butterworth high pass filter. Directional changes of the image and a blurred version of it are obtained by wavelet transform in the second phase. In ROI definition the upper and lower jaws are first separated using the integral intensity projection and then a region containing the desired edge lines are defined. In the final stage, some morphological operations are applied to isolate the teeth based on separating edge lines.
The evaluation of the teeth segmentation is measured by isolating accuracy and visual inspection. Experimental results with 90.6% isolation accuracy of total 681 teeth illustrate that the proposed method is more efficient that the existing algorithms.

Povzetek: Predstavljena je izvirna metoda analize posnetkov zob za namene forenzične identifikacije in verifikacije.

1 Introduction

X-ray radiographs have greatly been used within a variety of medical images. One of the common usages of X-ray imaging is in dentistry and forensic odontology. As tooth is the hardest tissue in our body, it plays an important role in forensic medicine. Individual characteristics such as fingerprints, pupils and face are not always possible for postmortem identification, particularly under the critical circumstances [17]. There are situations such as natural phenomenon (tsunami, hurricane, earthquake, etc.), terrorist attacks, airplane crashes and bomb explosion where victims cannot be identified by visual means. This is where dental features become important for forensic experts [11].

It is widely accepted that image segmentation is the most challenging part of the process of feature extraction from dental X-ray images. In the recent years, several approaches in image segmentation have been introduced and made progress in segmentation in order to overcome the existing shortcomings. The biggest challenges in this process are low quality of X-ray images, noise, and low contrast. However, one of the major problems in dental X-ray images is similarity of the pixel intensities between gum tissue and teeth. Although the inhomogeneity in pixel intensities has several effective factors, the basic problem is the device that produces these radiations [1].

Different methods, including thresholding-based segmentation, edge-based segmentation, clustering-based

Figure 1: Similarity between gum tissue and teeth in a dental X-ray image.

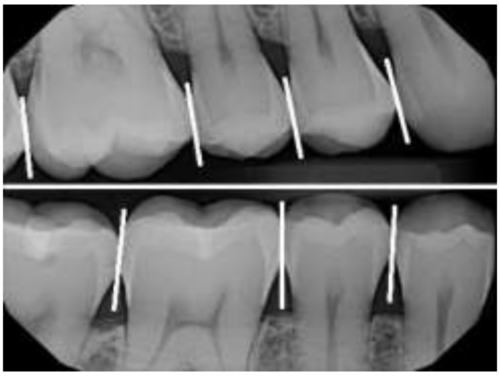

Figure 2: Separating lines for teeth segmentation.

segmentation and region-based segmentation, are being used among automatic processes for teeth segmentation. Thresholding-based techniques rely mainly on the distribution of pixel intensities and they use the information based on the single-band image. Edge-based segmentation methods are prone to produce disjoint edges. Clustering-based methods require training samples; for instance, K-means clustering requires initialization for the number of clusters k. Region-based techniques require objects with similar features in order to segment. These algorithms can segment high contrast simple medical images without noise [15].

The structure of desired segments should be homogeneous. For more complex image segmentation problems, a combination of mentioned segmentation algorithms can be used. Al-sherif, Guo & Ammar [2] use a two-step thresholding technique to binarize the image and then they separate teeth by finding the minimum cumulative energy path. Nomir & Abdel-Mottaleb [3] start segmentation using iterative thresholding followed by adaptive thresholding to segment the teeth from both the background and the bone areas. To separate individual teeth, they use vertical integral protection. Ølberg & Goodwin [4] proposed a path-based technique to segment a dental X-ray image into individual teeth. Abdel-Mottaleb et al. [5] first separate the teeth from the background of the image using a two-step threshold method. In the second stage, they separate each tooth using integral projection.

This study aims to find an automatic approach for teeth segmentation of dental X-ray images with higher accuracy. We propose a novel method that segments the bitewing images according to the edge lines between crowns of the teeth.

2 Application of wavelet transform

The proposed method consists of two steps; first, separating upper and lower jaws and second, finding the angle of edge lines between the teeth crowns and using morphological operation to separate each tooth according to the corresponding line.

Several phases are required to convert a dental X-ray image to the extracted features of each tooth as follows:

- Preprocessing
- Edge detection
- ROI definition

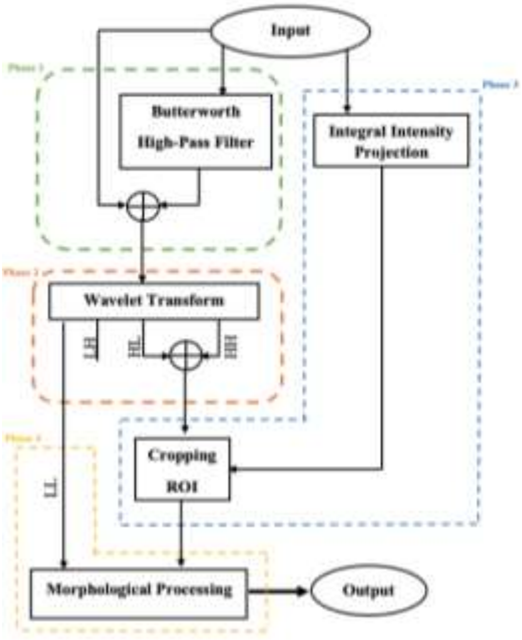

Figure 3: Block diagram of the proposed method.

- Teeth separation

2.1 Preprocessing

The nature of intra-oral radiographs includes poor image quality and so an efficient technique for image enhancement is required. Enhancement is an essential step in preprocessing of X-ray images due to poor quality, noise, unclear region boundaries [6]. Image enhancement techniques are applied in the new method proposed in this paper to reduce noise and increase contrast between different layers of the image [7]. Several efficient sharpening techniques have been employed to enhance dental X-ray images. The newly introduced method is done among homomorphic High Pass Filter (HPF), morphological top hat and bottom hat filter, Butterworth HPF and Gaussian HPF. The results can be seen in Figure 4.

It can be seen that the sharpened image by Butterworth HPF has lighter teeth and darker gums. The advantages of Butterworth HPF have been considered in this method by employing a general transfer function as follows:

$$H(u, v) = \frac{1}{1+[\frac{D_0}{D(u,v)}]^{2n}}$$

where D_0 is the cut-off frequency, n is the order of the filter and D(u, v) is the distance between a point (u, v) in the frequency domain and the center of frequency plane.

It has been found that the sharpened image contains high contrast between gap regions and the teeth that makes it easier to find the edge lines.

2.2 Edge detection

Edge detection is one of the effective methods to perform image segmentation. There are various types of edge detector operators such as Canny operator, Sobel operator, Prewitt operator, Robert's operator and LoG operator. Various disadvantages have been found about these

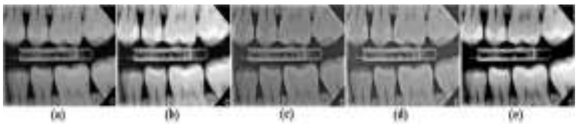

Figure 4: Comparison of sharpening methods. (a) input image, (b) morphological top hat / bottom hat, (c) homomorphic HPF, (d) Gaussian HPF, (e) Butterworth HPF.

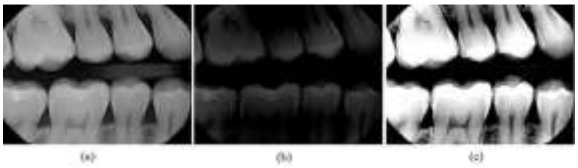

Figure 5: Dental image enhancement. (a) input image, (b) Filtered image, (c) Sharpened image.

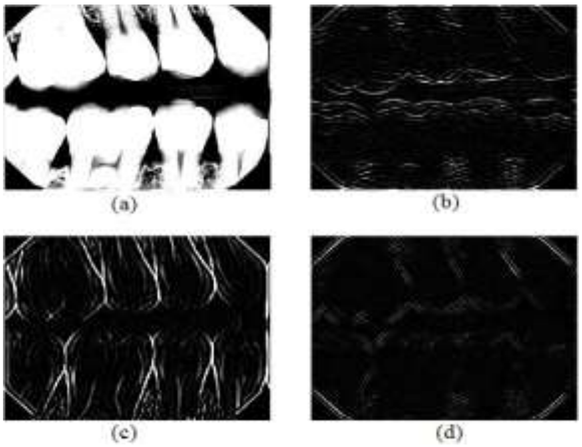

Figure 6: Bitewing X-ray image after decomposition by wavelet transform. (a) approximation, (b) horizontal details, (c) vertical details, (d) diagonal details.

methods as difficulties with detection of minor details, and a need to have high quality images to perform the edge detection operators in a satisfiable level [4]. Thus, in noisy images or low-quality images, these methods are not able to distinguish between edges and noise components.

A technique for edge detection that can overcome the mentioned problem is to use discrete wavelet transform (DWT) [8]. Down sampling in each sub-band of DWT leads to information loss in the output image. Therefore, Stationary Wavelet Transform (SWT) has been employed in the proposed method to overcome this loss.

The process of applying SWT to an image can be represented as a set of filters [9]. As shown in Figure 6, the image is divided into four bands including LL (approximation), LH (horizontal details), HL (vertical details), and HH (diagonal details). The letters H and L represent High pass and Low pass filtering respectively in each stage.

Among these three detailed images (horizontal, vertical and diagonal) we only need two bands of vertical and diagonal details in order to separate teeth in each jaw. A simple solution for this challenge is to combine vertical and diagonal details.

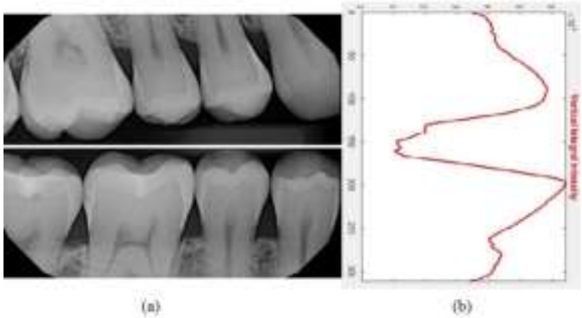

Figure 7: Gap finding between upper and lower jaw. (a) input image, (b) vertical intensity projection.

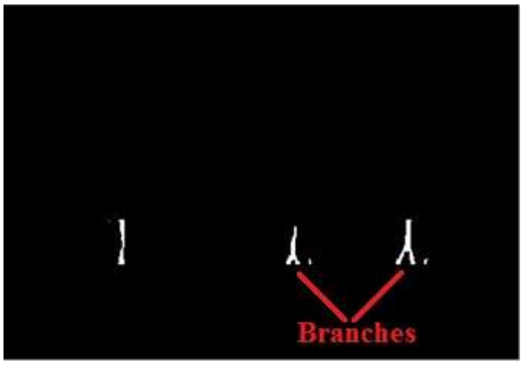

Figure 8: Branches of the edge lines in lower jaw.

2.3 ROI definition

The first step in region of interest (ROI) definition phase is jaw separation by finding the gap between jaws. Vertical intensity projection has been used for jaw separation. For the given image with intensity function I(x, y), the vertical intensity projection is defined as follows:

$$V(x) = \sum_{y=y_1}^{y_2} I(x, y)$$

The second step in ROI definition is cropping the region that contains crowns. Once cropped, details in the region containing gum tissue and roots cannot be seen anymore.

2.4 Morphological processing

After separating the image (containing edge lines) into two upper and lower jaws, it is needed to break branches of the existing edge lines. For this purpose, the morphological operations are used to skeletonize the edge lines and break all the branches, because only those parts of edge lines are of interest where crowns are connected.

After breaking the branches, small objects and noise in the binary image can be removed and the orientation of the separating edge lines in both upper and lower jaws can be found. By knowing the orientation of the separating lines, the desired structuring element can be defined and then the morphological image opening can be applied to separate teeth from each other.

Opening an image A by a structuring element B is denoted by A ∘ B and is defined as below:

$$A \circ B = (A \ominus B) \oplus B$$

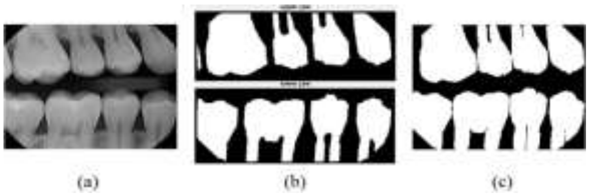

Figure 9: Morphological processing. (a) input image, (b) the opened binary images of upper/lower jaw, (c) the thickened image of the stitched image.

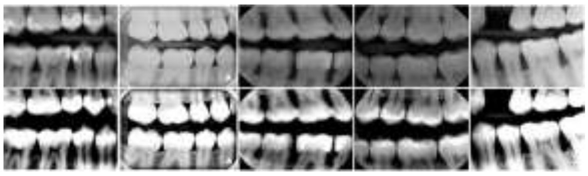

Figure 10: Upper row: original input images; lower row: sharpened Images by Butterworth HPF.

Morphological opening removes the regions of an object that cannot contain the structuring element. It breaks thin connections, smooths object contours and removes thin protrusions [10]. This leads to separated teeth in both upper and lower jaws. Finally, morphological image thickening is applied to retrieve size decrement due to image opening.

3 Results and discussion

3.1 Experimental results

First of all, the dental X-ray radiographs are required to get enhanced due to low quality and contrast. Different techniques have been used for this purpose by different authors; for instance, the morphological top-hat and bottom-hat filtering is used to increase contrast in medical images [11]; [7]; [6]; [12]; [13]; [14]; [15]; [16]; [4]. The histogram equalization as well as a combination of homomorphic and Butterworth HPF for image enhancement are employed for this purpose [17]; [18]; [19]; [20].

To decide which type of filtering results better, a comparison is done among four well-known types of medical images filtering. Table 1 shows the comparison of four bitewing X-ray images based on Peak Signal-to-Noise Ratio (PSNR) value of the input image and the sharpened image.

As can be seen in Figure 10, by applying Butterworth HPF, the teeth parts become lighter and the gum parts become darker that means the increment of contrast in the image.

Expanding the histogram of the image by sharpening strengthens the differences between various tissues in dental X-ray images. This prepares the image for finding directional details in the next phase. The gap between upper and lower jaw creates a valley in the graph of the vertical integral intensity projection. Hence, it can be concluded that this is a suitable approach to separate jaws.

The next step in ROI definition is to remove the undesired details such as roots and top of the teeth. Morphological operators are applied to obtain separating lines. Then, the binary version of approximation image is opened by separating edge lines. In the final stage, the location of individual teeth and extract them has been found by labeling connected components.

PSNR (dB)				
Filtering Type				
Butterworth HPF	35.23	36.27	36.73	35.77
Morphological Top/ Bottom-hat	31.07	34.06	33.32	33.42
Gaussian HPF	34.56	35.92	36.3	35.66
Homomorphic HPF	34.27	35.74	35.66	35.2

Table 1: PSNR of filtering in dental X-ray images.

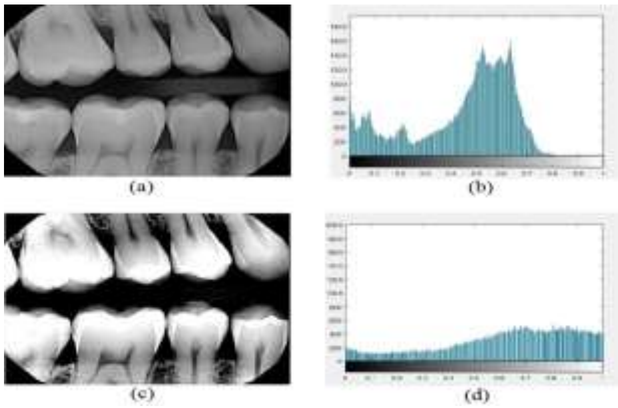

Figure 11: Contrast increment. (a) input image, (b) histogram of the input image, (c) sharpened image, (d) histogram of the sharpened image.

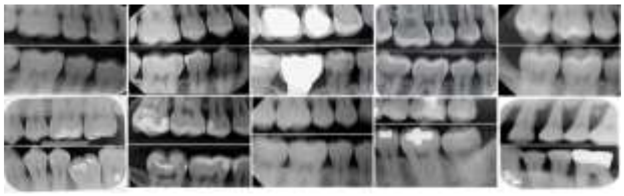

Figure 12: Some examples of jaws separation.

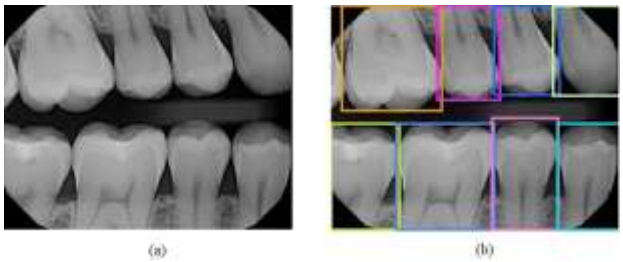

Figure 13: Teeth detection. (a) original input image, (b) bounding box of each tooth.

3.2 Evaluation

The algorithm is implemented in MATLAB R2016b, using an Intel(R) Core(TM) i5 CPU at 1.70GHz and 2.40GHz with 4GB RAM in a Microsoft Windows 8.1 Pro environment.

Segmentation method	Correctly separated in upper jaw	Correctly separated in lower jaw	Total isolation accuracy
Abdel-Mottaleb et al. [5]	169/195 – 86.66%	149/181 – 82.32%	318/376 – 84.57%
Nomir & Abdel-Mottaleb [3]	329/391 – 84.14%	293/361 – 81.16%	622/752 – 82.71%
Al-Sherif et al. [2]	1604/1833 – 87.5%	1422/1692 – 84%	3026/3525 – 85.8%
Ølberg & Goodwin [4]	300/336 – 89.3%	270/306 – 88.2%	570/642 – 88.78%
The proposed method	325/351 – 92.6%	292/330 – 88.5%	617/681 – 90.6%

Table 2: The result of teeth segmentation methods.

Segmentation method	Correctly separated in upper jaw	Correctly separated in lower jaw	Total isolation accuracy
Ølberg & Goodwin [4]	308/351 – 87.7%	285/330 – 86.3%	593/681 – 87%
The proposed method	325/351 – 92.6%	292/330 – 88.5%	617/681 – 90.6%

Table 3: The comparison using the same database.

85 bitewing X-ray images have been used for teeth segmentation experiments with the total 681 separable teeth. Teeth are divided into two groups as the teeth in the upper jaw and the teeth in the lower jaw. The evaluation of segmentation is based on the isolation accuracy.

$$\text{Isolation Accuracy} = \frac{N_c}{N_t} \times 100\%$$

where Nc is the number of teeth that are correctly isolated and Nt is the total separable teeth.

In the proposed method, 325 teeth in the upper jaw and 292 teeth in the lower jaw are separated correctly out of the total 351 and 330 teeth in the upper and lower jaws, respectively.

Among plenty of different approaches, Table 2 shows the isolation accuracy of four efficient methods for upper/lower jaw and overall teeth separately. It has been shown that the proposed method has the highest performance in correctly separating the teeth at both upper and lower jaws. Consequently, it attains the best isolation accuracy among the other state of the art methods.

The proposed method has also been compared with Ølberg & Goodwin [4], with the best performance in comparison with the other state of the art method, using the same database containing 681 separable teeth and the result of this comparison is shown in Table 3.

Ølberg & Goodwin in [4] use morphological top-hat and bottom-hat filtering to enhance the input image and then they separate teeth by using path-based method. It can be seen that the proposed method achieves better result and can detect and separate the teeth in upper and lower jaws with higher accuracy.

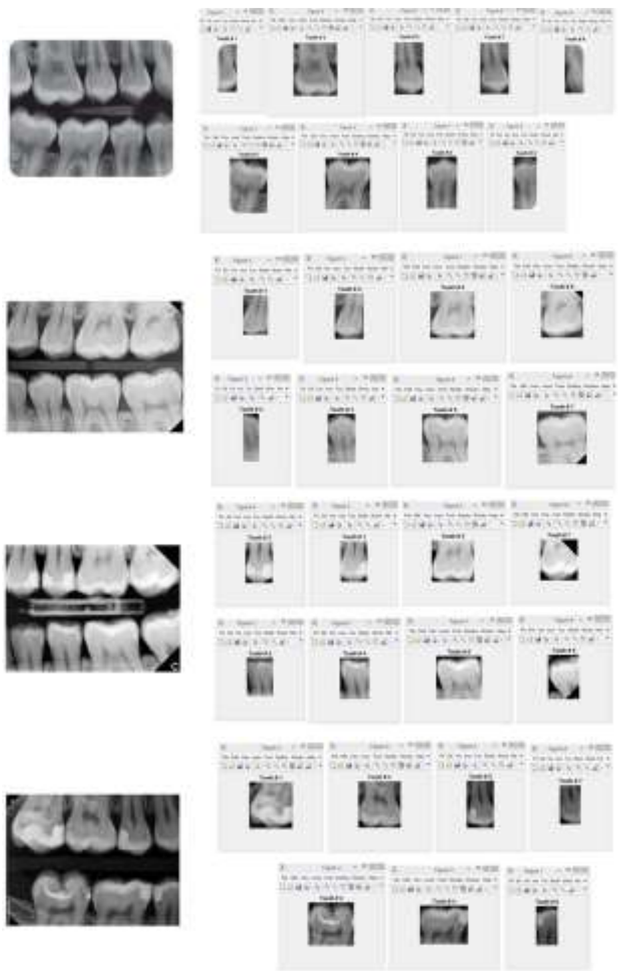

Figure 14: Some examples of the final results.

4 Conclusions

Poor quality of the X-ray images prevents the teeth separation and causes under- or over-segmentation. To solve this problem, a novel method for separating the bitewing X-ray image into individual teeth has been introduced in this paper. At the first phase of the proposed method, the resolution of the image is enhanced and afterwards a wavelet-based edge detection followed by some morphological operations segments and separates each tooth.

The experimental result of 90.6% in terms of isolation accuracy on a database consisting of 681 teeth in 85 bitewing X-ray images has been employed in this paper to show the superiority of the proposed method in comparison to the state-of-the-art teeth segmentation methods. The method can be used as a part of an ADIS for matching purpose.

5 References

[1] Chunming Li, Rui Huang, Zhaohua Ding, Chris Gatenby, Dimitris Metaxas, and John Gore. A variational level set approach to segmentation and bias correction of images with intensity inhomogeneity. In: Metaxas D., Axel L., Fichtinger G., Székely G. (eds) Medical image computing and

computer-assisted intervention. *MICCAI 2008*. Lecture Notes in Computer Science, Springer, Berlin, Heidelberg, 5242:1083-1091, 2008. https://doi.org/10.1007/978-3-540-85990-1_130.

[2] Nourdin Al-sherif, Guodong Guo, and Hany H. Ammar. A new approach to teeth segmentation. *2012 IEEE International Symposium on Multimedia*, Irvine, CA, 145-148, 2012. https://doi.org/10.1109/ism.2012.35.

[3] Omaima Nomir, and Mohamed Abdel-Mottaleb. A system for human identification from X-ray dental radiographs. *Pattern Recognition*, Elsevier, 38(8):1295-1305, 2005. https://doi.org/10.1016/j.patcog.2004.12.010.

[4] Jan-Vidar Ølberg, and Morten Goodwin. Automated dental identification with lowest cost path-based teeth and jaw separation. *Scandinavian Journal of Forensic Science*, Sciendo, 22(2):44-56, 2016. https://doi.org/10.1515/sjfs-2016-0008.

[5] Mohamed Abdel-Mottaleb, Omaima Nomir, Diaa Eldin Nassar, Gamal Fahmy, and Hossam Hassan Ammar. Challenges of developing an automated dental identification system. *46th Midwest Symposium on Circuits and Systems*, IEEE, Cairo, 1:411-414, 2003. https://doi.org/10.1109/mwscas.2003.1562306.

[6] Jindan Zhou, and Mohamed Abdel-Mottaleb. A content-based system for human identification based on bitewing dental X-ray images. *Pattern Recognition*, Elsevier, 38(11):2132-2142, 2005. https://doi.org/10.1016/j.patcog.2005.01.011.

[7] Gamal Fahmy, Diaa Nassar, Eyad Haj-Said, Hong Chen, Omaima Nomir, Jindan Zhou, Robert Howell, Hany H. Ammar, Mohamed Abdel-Mottaleb, Anil K. Jain. Towards an automated dental identification system (ADIS). In: Zhang D., Jain A.K. (eds) Biometric authentication. *ICBA 2004*. Lecture Notes in Computer Science, Springer, Berlin, Heidelberg, 3072:789-796, 2004. https://doi.org/10.1007/978-3-540-25948-0_107.

[8] Darshan Bhavesh Mehta, and Harsha Kosta. Image compression using discrete cosine transform. *International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)*, 4(4):6796-6799, 2016. DOI: 10.15680/IJIRCCE.2016. 0404073.

[9] Kamlesh Kumar, Nadir Mustafa, Jian-Ping Li, Riaz Ahmed Shaikh, Saeed Ahmed Khan, and Asif Khan. Image edge detection scheme using wavelet transform. *11th International Computer Conference on Wavelet Active Media Technology and Information Processing (ICCWAMTIP)*, Chengdu, 261-265, 2014. https://doi.org/10.1109/iccwamtip.2014.7073404.

[10] Rafael C. Gonzalez, and Richard E. Woods. *Digital image processing, 2nd Edition*. Pearson. 2002.

[11] Eyad Haj Said, Diaa Eldin Nassar, Gamal Fahmy, and Hany H. Ammar. Teeth segmentation in digitized dental X-ray films using mathematical morphology. *IEEE Transactions on Information Forensics and Security*, 1(2):178-189, 2006. https://doi.org/10.1109/tifs.2006.873606.

[12] Mohammad H. Mahoor, and Mohamed Abdel-Mottaleb. Automatic classification of teeth in bitewing dental images. *International Conference on Image Processing*, ICIP '04., Singapore, 5:3475-3478, 2004. https://doi.org/10.1109/icip.2004.1421863.

[13] Eyad Haj Said, Gamal Fahmy, Diaa Eldin Nassar, and Hany H. Ammar. Dental x-ray image segmentation. *Proceedings of SPIE - The International Society for Optical Engineering*, United States, 5404:409-418, 2004. https://doi.org/10.1117/12.541658.

[14] Jindan Zhou, and Mohamed Abdel-Mottaleb. Automated human identification based on dental X-ray images. *Proceedings of Biometric Technology for Human Identification*, United States, 5404:373-380, 2004. https://doi.org/10.1117/12.542689.

[15] Mohammad H. Mahoor, and Mohamed Abdel-Mottaleb. Classification and numbering of teeth in dental bitewing images. *Pattern Recognition*, Elsevier, 38(4):577-586, 2005. https://doi.org/10.1016/j.patcog.2004.08.012.

[16] Faraein Aeini, and Fariborz Mahmoudi. Classification and numbering of posterior teeth in bitewing dental images. *3rd International Conference on Advanced Computer Theory and Engineering (ICACTE)*, IEEE, Chengdu, V6-66-V6-72, 2010. https://doi.org/10.1109/icacte.2010.5579369.

[17] Noorhayati Mohamed Noor, Noor Elaiza Abdul Khalid, Mohd Hanafi Ali, and Alice Demi Anak Numpang. Enhancement of soft tissue lateral neck radiograph with fish bone impaction using adaptive histogram equalization (AHE). *Second International Conference on Computer Research and Development*, IEEE, Kuala Lumpur, 163-167, 2010. https://doi.org/10.1109/iccrd.2010.84.

[18] Thangavel Kuttiyannan, R. Manavalan, and Laurence Aroquiaraj. Removal of speckle noise from ultrasound medical image based on special filters: comparative study. *ICGST-GVIP Journal*, 9(3):25-32, 2009.

[19] Peyman Rahmati, Ghassan Hamarneh, Doron Nussbaum, and Andy Adler. A new preprocessing filter for digital mammograms. In: Elmoataz A., Lezoray O., Nouboud F., Mammass D., Meunier J. (eds) Image and signal processing. *ICISP 2010*. Lecture Notes in Computer Science, Springer, Berlin, Heidelberg, 6134:585-592, 2010. https://doi.org/10.1007/978-3-642-13681-8_68.

[20] Vijayakumari Pushparaj, Ulaganathan Gurunathan, and Banumathi Arumugam. An effective dental shape extraction algorithm using contour information and matching by mahalanobis distance. *Journal of Digit Imaging*, Springer, 26(2):259–268 2013. https://doi.org/10.1007/s10278-012-9492-4.