An Adaptive Thresholding Method for Segmenting Dental X-Ray Images

Muhamad Rizal Mohamed Razali[1, 2], Waidah Ismail[2], Nazatul Sabariah Ahmad[3], Mahadi Bahari [4], Zulkifly Mohd Zaki[2] and Abduljalil Radman[2]

[1]Penang Skills Development Centre, Pulau Pinang, Malaysia.
[2]Faculty of Science and Technology, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia.
[3]Faculty of Dentistry, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia.
[4]Faculty of Computing, Universiti Teknologi Malaysia, Johor, Malaysia.
rizal@psdc.org.my

***Abstract*— Thresholding is a way of segmenting an image into foreground and background according to a fixed constant value called a threshold. Image segmentation based on a constant threshold leads to unsatisfactory results with dental X-ray images due to the uneven distribution of pixel intensity. In this paper, an adaptive thresholding method is proposed to attain promising segmentation results for dental X-ray images. The Mean, Median, Midgrey, Niblack, and OTSU thresholding methods are utilized to delineate the acceptable range of threshold values to be applied for segmenting X-ray images. Experimental results showed that the Median method provides consistency in achieving the best range of threshold values which is between 57 and 86 in greyscale.**

***Index Terms*— Age Estimation; Image Segmentation; Image Thresholding.**

I. Introduction

Forensic dentists use teeth information for determining the age, race, gender, and ethnic of unidentified human beings. Dental X-ray image is one of the evidence used in forensic dentistry; and correct age estimation based on dental X-ray images is regarded very important and useful in a broad range of different fields including forensic dentistry [1]. In fact, the current process of estimating the age using dental X-ray image is done manually by the forensic dentist through dividing the image into four quadrants, where each quadrant starts from the incisor teeth to the end of arch of the molar teeth [2]. However, this process is tedious and lengthy as well as suffers from the presence of a non-standard precision because it depends on the forensic dentist's skill. All these disadvantages limit its feasibility and reliability. Indeed, this process can be done automatically by image segmentation techniques via classifying the dental X-ray image into foreground (i.e. teeth area) and background (i.e. other areas). Then, the four quadrants are extracted accordingly. One of the promising techniques for segmenting X-ray images into background and foreground is by applying an adaptive thresholding technique. Adaptive thresholding changes the threshold dynamically over the image so as to overcome uneven distribution of pixel intensity [3,4]. In this paper, a new adaptive thresholding method is proposed with the aim of helping forensic dentists in estimating the dental age using X-ray images. The proposed method is based on finding the suitable adaptive threshold values using several thresholding methods which are Mean, Median, Midgrey, Niblack and OTSU.

The remainder of this paper is organized as follows. The related work is presented in Section II. Section III explains the data collection for experiments. The proposed method is introduced in Section IV while the evaluating results are discussed and analyzed in Section V. Finally, discussion and conclusion are drawn in Section VI.

II. Related Work

This section focus on previous research of dental forensic and image processing for dental age estimation.

A. Dental Forensic

There are many methods employed in dental age estimation including radiographs, tooth prints, photographic studies and molecular methods. In fact, radiographs-based methods [5-11] were proven their efficacy in dental age estimation and had been wider used by forensic dentists. Demirjian et al. [5] divided tooth information into eight stages. Eight stages of calcification for each tooth were identified and described, and each stage was allocated a score. The sum of these scores gives an evaluation of the subject's dental maturity, and the dental age is then calculated based on these scores and the related sex specific tables. Nolla [6] also developed a method to assess the dental age. In Nolla's method, the stages of the dental development were divided into ten stages through each of which every tooth passed, where each stage scored with a number. Next, these scores were summed to give a total score, and that was divided by the number of teeth to give the dental age [10]. Haavikko et al. [7] adopted an age estimation method on the basis of determining one of twelve radiographic stages of each permanent teeth. In 2001, Willems et al. [8] adjusted scores using tooth stages of Demirjian et al. [5] to calculate the subject's dental maturity. In [2], the authors formulated a regression model for dental age estimation in Malaysian children population using Cameriere's method [11]. Cameriere et al. [11] proposed a new concept of estimating chronological age in children by measuring the open apices in seven mandibular teeth on radiographs. Recently, Lucas et al. [9] proved the potential of using root pulp visibility [12] to determine whether or not a subject of unknown date of birth is under or over the 18-year old. However, the majority of these techniques indicate dental X-ray images are an important for age estimation. Additionally, image segmentation to predict the dental development is the main process before proceed further in calculating the dental age.

As the proposed method in this paper aims to help forensic dentist in estimating the dental age based on Demirjian's method [5], more details about Demirjian's method is given in what follows. Demirjian's method [13] was introduced in 1973 to estimate the dental age using panoramic radiograph. It is based on the teeth development, where the teeth development refers to the tooth changes from initial calcium to complete apex. First, the teeth development is divided into eight stages and each stage is allocated a score. Then, the teeth area is divided into four quadrants, each quadrant consists of seven or eight teeth begin with central incisor into the second molar as shown in Figure. 1 Next, the forensic dentist observes the teeth in quadrant number two and quadrant number three, if the references tooth in quadrant number two are not clear, the forensic dentist have to look to the corresponding tooth in quadrant number one, whereas the tooth in quadrant number three are not clear, the forensic dentist have to refer to the corresponding tooth in quadrant number four. Finally, the sum of the scores calculated based on percentile standards given separately for boys and girls estimates the dental age of an individual. More details about Demirjian's method can be found in [5]. Thus, image processing techniques might play an important role in segmenting the teeth area as well as exposing the dental development which facilitate the dentist's work in calculating the dental age.

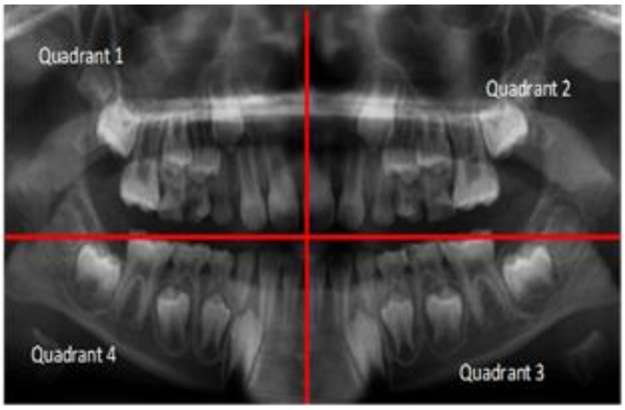

Figure 1: The arrangement of quadrants based on Demirjian's method

B. Image Processing for Dental Age Estimation

Digital image processing algorithms are widely used in practical technology such as medicine [14-15], forensics [16], and machine vision applications [17-18]. Thresholding is one of the quite famous algorithms in manipulation digital images. Thresholding techniques are usually used for image segmentation [19] through classifying the image into foreground and background. Often, X-ray image are segmented using thresholding techniques [20-22]. In [20], a method based on OTSU's threshold [23] was proposed to extract knee components from X-ray images. In fact, the arrangement of knee components is straight forward and therefore easy to extract, while the teeth structure arrangement is complex and sometime overlapped. OTSU's threshold embedded with watershed algorithm was also utilized to segment the teeth area from X-ray images [21]. However, OTSU-based methods are ineffective methods in segmenting dental X-ray images [21]. In a different approach [22], the teeth segmentation of dental X-ray images was firstly started by applying a morphological operation to stretch the contrast, then an edge operator to obtain the coarse contour was applied, and finally the OTSU's threshold was used to obtain the fine contour points. From our view point, the majority of aforementioned methods are based on single threshold value which is not applicable in segmenting X-ray images due to the uneven distribution of pixel intensity in such images.

On the other hand, Al-amri et al. [24] tested five thresholding methods on three satellite images. The tested methods were Mean, P-tile, Histogram Dependent Technique, Edge Maximization Technique, and visual technique. The authors claimed that their algorithm is able to obtain an automatic threshold value for satellite image segmentation. Unfortunately, the authors did not mention the range of the threshold values which produces the best segmentation result. Moreover, methods on color images might not be suitable for X-ray images. In other method [25] for an automated dental image segmentation using threshold, the authors applied top-hat and bottom-hat filters to enhance the image contrast before applying the threshold for segmentation. In particular, X-ray image segmentation using fixed threshold value might not be applicable because of the huge variations of intensities in such images. Hence, the adaptive thresholding method proposed in this paper aims to narrow down the scale of the threshold values from 0 to 255 to a certain range so as to segment the whole teeth area of dental X-ray images accurately.

III. DATA COLLECTION

In this work, the experiments were carried out on a set of 200 dental X-ray images obtained by the Faculty of Dentistry Universiti Sains Islam Malaysia. The images were collected from patients below fifteen years old, which means that the process of tooth replacement from primary to permanent still occurs. Indeed, human being has two sets of teeth, primary and permanent. The primary teeth are usually replaced by permanent teeth at the age of six and the last primary teeth exuviates usually around age of twelve. Thus, the collected images are affected by overlap teeth and therefore more challenge in segmentation.

IV. PROPOSED AN ADAPTIVE THRESHOLDING METHOD

The aim of the proposed an adaptive thresholding method is to obtain the appropriate range of threshold values for segmenting dental X-ray images with the aim of helping forensic dentist in estimating the dental age. The proposed method aids to narrow down the scale of the threshold value from 0 to 255 greyscale to a certain range values, where the gap of the threshold value closer and simultaneously able to segment the whole teeth area of dental X-ray images. The proposed method starts by converting the X-ray image into greyscale image. Following this, the threshold to segment each X-ray image is obtained by five thresholding methods which are the Mean, Median, Midgrey, Niblack and OTSU. Next, the suitable range of threshold values is obtained on the basis of statistics and histogram of these thresholds over all image. Figure. 2 shows the block diagram of the proposed method. In the following subsections, a description of Mean, Median, Midgrey, Niblack and OTSU threshold methods is provided.

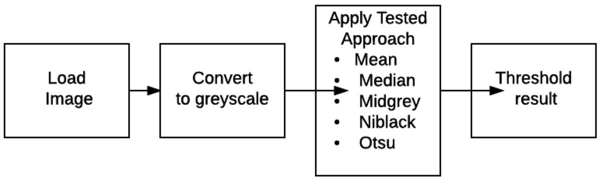

Figure 2: Block diagram of the proposed method

A. Mean

In this method, the mean value of all pixels is used as a threshold. The mean threshold ($\overline{X}$) is obtained by dividing the total value of pixels over the number of pixels as follows:

$$T = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} f_i(x, y) \quad (1)$$

where $f_i\,(x,y)$ is the pixel value at the pixel i, and n is the number of pixels in the image. The mean threshold works well with those images have uniform distribution.

B. Median

Here, the median refers to the middle pixel value from series of pixels n. Therefore, all the pixel values (y) are first sorted in ascending order. Then, the middle value is calculated through dividing the total number in the series (y) by two.

$$T = \frac{y}{2} \quad (2)$$

C. Midgrey

The midgrey threshold value is the lowest pixel value x_l added to the highest pixel value x_h and divided by two:

$$T = \frac{x_l + x_h}{2} \quad (3)$$

D. Niblack

The Niblack method uses the mean and standard deviation of the pixels to calculate the threshold as follows:

$$T = mean + k*standard\ deviation \quad (4)$$

where k is the brightness of the image (in our experiments sets to 0.1).

E. OTSU Threshold

The OTSU's threshold method first finds the mean of foreground (μ_1) and background (μ_2) for each grey scale value i as in Equations (5) and (6).

$$\mu_1(t) = \sum_{i=1}^{t} \frac{iP(i)}{q_1(t)} \quad (5)$$

$$\mu_2(t) = \sum_{i=t+1}^{I} \frac{iP(i)}{q_2(t)} \quad (6)$$

where $P(i)$ is the normalized frequency of i. The q refers to the total pixels of foreground q_1 and background q_2. The variance of foreground (σ_1^2) and background (σ_2^2) are then calculated by:

$$\sigma_1^2(t) = \sum_{i=1}^{t} [i - \mu_1(t)]^2 \frac{P(i)}{q_1(t)} \quad (7)$$

and

$$\sigma_2^2(t) = \sum_{i=t+1}^{I} [i - \mu_2(t)]^2 \frac{P(i)}{q_2(t)} \quad (8)$$

Finally, the threshold is obtained by the foreground and background variances as follows:

$$T = W_1\sigma_1^2 + W_2\sigma_2^2 \quad (9)$$

where W refers to the sum of the variances.

V. RESULTS AND DISCUSSIONS

The effectiveness of the proposed method is evaluated using 200 dental X-ray images collected by dentists in the Faculty of Dentistry Universiti Sains Islam Malaysia. For each subject, there is an X-ray image taken in the frontal pose. To evaluate the proposed an adaptive threshold method using these images, the five threshold methods including Mean, Median, Midgrey Niblack and OTSU are first applied on each X-ray image in order to obtain the threshold value corresponds to each method. Then, the histogram of threshold values, obtained by Mean, Median, Midgrey Niblack and OTSU, over all images are drawn. Finally, the histogram pattern of these thresholds is analyzed with the aim of extracting the suitable range of threshold values to be used for image segmentation.

Figure 3 depicts the distribution of threshold values over all methods. From Figure 3, the pattern of thresholds distribution shows almost similar pattern for all methods excepts for Midgrey method. The Midgrey method produces stagnant graph because the Midgrey method computes the threshold value by adding the lowest pixel value (i.e. 0) to the highest pixel value (i.e. 255) and then dividing the result by two (Equation (3)). As a result, 199 images of the 200 images produce similar threshold value which is 127 and only one image (Figure. 4) produces different threshold value which is 134. The reason behind that is the lowest pixel value for that image is 19 rather than 0.

Although the pattern for all methods is almost similar, but each method has its own threshold value corresponds to each image. In order to find the suitable range of threshold values based on the threshold distributions, the descriptive statistical metrics are applied. The average and standard deviation are well-known metrics in descriptive statistic. Importantly, the calculated averages for Mean, Median, Midgrey, Niblack and OTSU methods are 80.9, 68.5, 127.0, 86.4 and 112.1, respectively. Whereas standard deviations are 8.5, 5.1, 0.5, 9.6 and 20.7 for Mean, Median, Midgrey, Niblack and OTSU methods, respectively. In addition, the range of threshold values for each method is obtained through subtracting the minimum threshold value from the maximum threshold value. As a result, the range of threshold values are 37, 29, 7, 39 and 73 for Mean, Median, Midgrey, Niblack and OTSU methods, respectively.

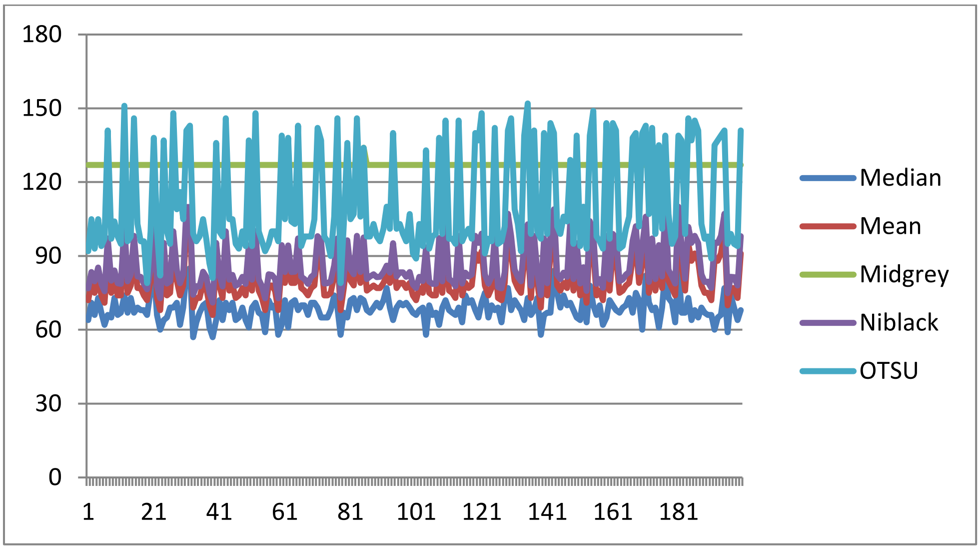

Figure 3: The distribution of the threshold values among the tested method

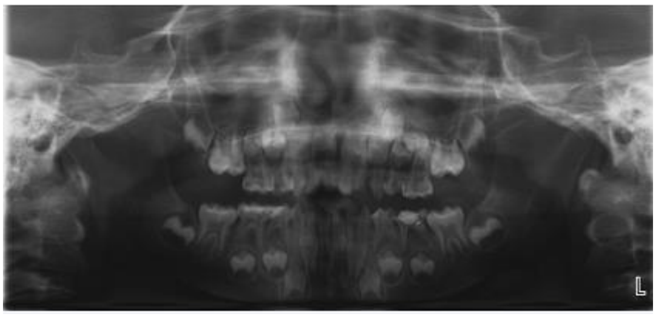

Figure 4: The image of the teeth x-ray that has lowest pixel value was 19

These statistical results reveal that the Midgrey method attains the lowest range threshold and standard deviation values which are 7 and 0.5, respectively. Hence, the range of threshold values of the Midgrey method is theoretically regarded the suitable range of thresholds for segmenting the images. On the contrary, the segmentation results using Midgrey method showed that this method extract less number of teeth compared to Median and Mean methods. Figure. 5 illustrates an example of the segmentation results obtained by all threshold methods.

By visual inspection, the Median method exposes the best segmentation results (Figure. 5 (c)) among all methods, where it shows larger number of teeth. Statistically, Table 1. summarizes the minimum, maximum, average, standard deviation and range of threshold values of all methods.

Table 1
The Summary of Values Obtained by All Methods

Parameter	Mean	Median	Midgrey	Niblack	OTSU
Minimum	66	57	127	71.07	79
Maximum	103	86	134	110.2	152
Average	80.9	68.5	127.0	86.4	112.1
Standard deviation	8.5	5.1	0.5	9.6	20.7
Threshold range	37	29	7	39.13	73

As can be seen from Table 1, the Median method also obtains low range of threshold and standard deviation values compared to Mean, Niblack and OTSU methods which are 29 and 5.1, respectively. In this research, the method that can segment larger number of teeth and achieves low range of threshold and standard deviation values is considered the best thresholding method for segmenting the dental X-ray images. Obviously, the Median method achieves these conditions.

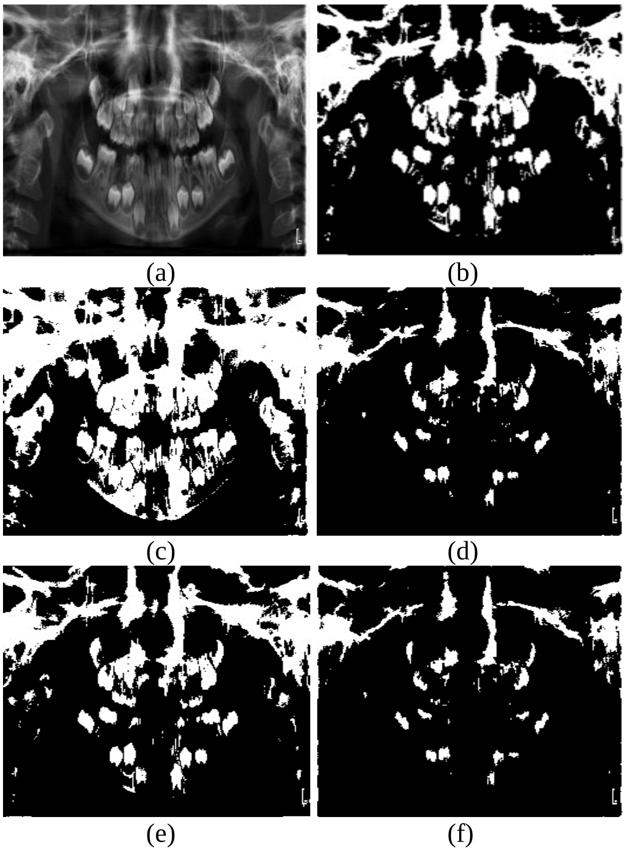

Figure 5: Image segmentation by all threshold methods (a) original image (b) Mean (c) Median (d) Midgrey (e) Niblack and (f) OTSU

VI. CONCLUSION

In this paper, a new adaptive thresholding method is proposed with the aim of helping forensic dentists in estimating the dental age using X-ray images. The proposed method aims to narrow down the scale of the threshold values from 0 to 255 greyscale to a certain range in order to attain promising segment results before proceed further in estimating the dental age. In summary, five thresholding methods including Mean, Median, Midgrey Niblack and OTSU were used to extract the proper range of threshold values for segmenting dental X-ray images. These five methods were applied on all tested X-ray images to obtain the distribution of threshold values over all methods. By visual and statistical analysis, the Median method found to be fit with the experiment criteria, where it shows lowest range of threshold and standard deviation values and larger number of teeth segmentation. The obtained suitable threshold values for segmenting the teeth X-ray images ranges between 57 and 86. In the future work, the segmentation results will be used in segmenting the teeth area with edge-based techniques so as to improve the segmentation accuracy as well as define the accurate teeth for age estimation by Demirjian's method.

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