X-RAY IMAGE PROCESSING FOR TISSUE INVOLVEMENT-BASED CARIES DETECTION

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Abstract

X-ray images improvement is very important for early detection of dental caries, which prevents in some cases more futures complications. The low quality of these images is caused by low spatial resolution and the presence of artefacts and noise. This paper presents an effective approach for X-ray image processing for tissue involvement-based caries detection. It is based on contrast enhancement and noise suppression based on modified homomorphic wavelet filter. It uses adaptive wavelet packet shrinkage decomposition and adaptive threshold of wavelet coefficients to reduce noise components and to eliminate non-uniformity luminance distribution. For better visual observation of the detected caries the split and merge segmentation is applied.

1. INTRODUCTION

An accurate dental diagnosis will result in treatment, which will potentially use the benefit of non-invasive types of treatment at an earlier stage of caries development. X-ray images are most used for detecting caries, determining the depth of involvement and identifying the caries status. The "artifact" in diagnostic X-ray images can be presented as light or dark spots, lines, fogging, speckles, etc. [1]. The quantum noise is dominant and comes from the quantization of energy into photons. Photon noise results from the statistical nature of electromagnetic waves, which include visible light, x-rays and γ-rays with a probability distribution that is a Poisson distribution. It is not independent of the signal nor is it additive [1]. Metal artifacts severely degrade the image quality, particularly near metal surfaces [2].

X-ray image processing can help to obtain better results in caries detection.

The most enhancement methods, which are reported in the literature include classical homomorphic filtering, adaptive contrast stretching, and adaptive morphological transformation to obtain the enhanced image with a uniform illumination [3,4]. The algorithms based on combination of sharpening and enhancement method are used to overcome these problems. Three types of proposed compound algorithms are used: sharp adaptive histogram equalization (SAHE), sharp median adaptive histogram equalization (SMAHE) and sharp contrast adaptive histogram equalization (SCLAHE) [5]. They are useful applied on the detection of only three types of dental pathology, which are periapical radiolucency, widen periodontal ligament space and loss of lamina dura [6]. Wavelet discrete transform (WDT) and wavelet shrinkage are used to restore the blurred image getting better visual and statistical properties of images [7]. The wavelet thresholding scheme [8,9], recognizes that by performing a wavelet transform of a noisy image, random noise will be represented principally as small coefficients in the high frequency sub-bands. They can be set to zero, and so will be eliminated much of the noise in the image. For optimizing diagnosis of dental caries another approach was proposed [10]. It uses contrast limited adaptive histogram equalization (CLAHE) and homomorphic wavelet filtering for eliminating of non-uniformity luminance distribution of image and noise reduction. It shows good results for detecting of cervical caries and root caries.

In the case of tissue involvement-based caries is important to obtain information about the area of enamel destruction and the depth of the structural defect. For these considerations, a pre-processed stage, based on contrast enhancement and noise suppression based on modified homomorphic wavelet filter is first provided in the proposed approach, then for better visual observation of the detected caries, the split and merge segmentation is applied.

The rest of paper is organized as follows: In Section 2, the basics stages of the proposed approach are given; some experimental results and their interpretation are presented in Section 3 and in Section 4 - the Conclusion.

2. BASIC STAGES OF DENTAL X-RAY IMAGE PROCESSING

The flowchart of the main algorithm of the proposed approach is presented in Fig. 1.

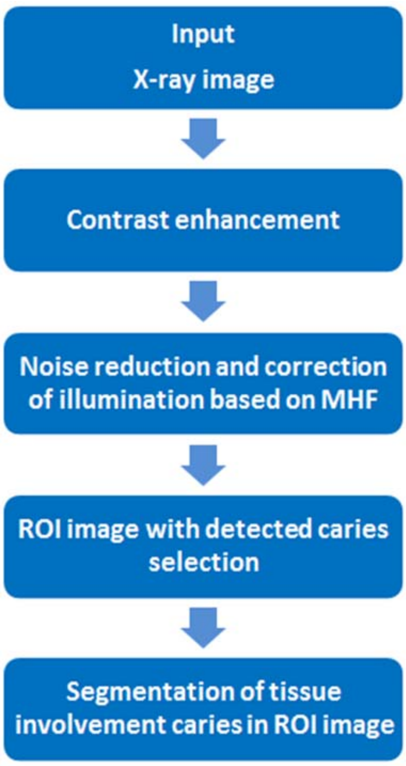

Figure 1. The flowchart of the main algorithm

The first step in the pre-processing stage is contrast enhancement. It includes CLAHE for contrast enhancement and morphological top & bottom hat operation for detail preservation capabilities [10]. The flowchart of this step is given in Fig. 2.

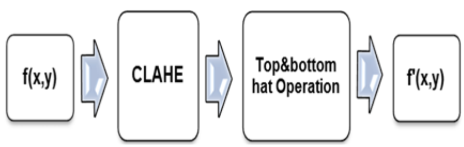

Figure 2. Flowchart of the contrast enhancement step

We propose to apply CLAHE to Y component of the X-ray image that is processing in YUV system as more effectiveness. We have chosen the form of histogram ('Distribution parameter') on the base of calculated PSNR and visually quality of the processed image in regard to obtain better diagnosis. Furthermore, the clip limit can be determined at the point with maximum on entropy curve of the image [11].

By using top-hat morphological operation, we can obtain details of the teeth as the edge, surface and size. An important application of top-hat transformation is in correcting some effects of non-uniform illumination. In this case, the background image is enhanced for better identification of the teeth and existing of caries. The bottom-hat operation aims to highlight the valleys of image [12]. In this case the objects are emphasized, which simplifies their segmentation from the background image. We propose to use an adaptive selection of the structuring element and its parameters for the morphological transform, which is based on calculated estimation parameters.

The next step includes noise reduction, based on modified homomorphic filter [10]. Using this filter, we convert the multiplicative Poisson noise model into additive. The modified homomorphic filter is based on wavelet packet transform (WPT). The WPT proposes more complete analysis and provides increased flexibility according to DWT. Based on the organization of the wavelet packet library, the decomposition was performed from a given orthogonal wavelets. As this number can be very large, it is important to find an optimal decomposition with respect to a conventional criterion. The classical entropy-based criterion is a common concept [13]. The Normal Shrink method is used for calculation the threshold value only of the detail sub-bands in the best shrinkage decomposition [14, 15]. This threshold can be adaptive calculated for the coefficients of each sub-bands in regard to reduce noise components and to eliminate non-uniformity luminance distribution.

The next stage is selection of region of interest (ROI), which is closed to the specific area with enamel destruction. It can be marked from the dentist.

As next, for better visual observation of the tissue involvement-based detected caries, the split and merge segmentation is applied.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The formulated stages of processing are realized by computer simulation in MATLAB 8.1 environment by using IMAGE PROCESSING and WAVELET toolboxes. For the experiments, 20 X-ray images of teeth with size 1797x1441 pixels are used. The original images have been done in jpeg file format. By processing they are converted in bmp format. The images are from clinical praxis of caries superficial, caries media and deep caries (caries profunda).

Table 1 presents the obtained averaging results of processing of all images. It shows the values of the objective quantitative estimation parameters such as PSNR, Signal to noise ratio in the noised image (SNR_f), Signal to noise ratio in the filtered image (SNR_g), Effectiveness of filtration (E_{FF}).

Table 1. Experimental results in pre-processing stage

Steps of pre-processing	PSNR [dB]	SNR_f [dB]	SNR_g [dB]	E_{FF} [dB]
CLAHE	24.563	-	-	-
Morphological processing	26.268	10.235	11.887	1.652
Noise reduction	29.284	11.887	13.594	1.707

The best results for contrast enhancement using CLAHE are obtained by bell-shaped form of histogram (Rayleigh distribution).

For morphological processing (MP) with disk-shaped structuring element and especially a diamond-shaped structuring element can be obtained well-defined outlines of some tissues in the teeth, but the values of the noised components in the X-ray images are greater. We have obtained the best results with cross structuring element of size 7x7.

Our best results for noise reduction stage are obtained by Coiflet wavelet packet functions, adaptive shrinkage decomposition (best tree) on the base of the second level and minimum of the Shannon entropy criteria, when hard penalized threshold was used. By experiments, when we used Daubechies db2 [16] wavelet packet function, the log energy and energy criteria the obtained effectiveness of filtration was smaller.

The original and pre-processed X-ray images in the presence of caries superficial are shown in Fig. 3 and Fig. 4, respectively.

Figure 3. Original X-ray image with indication of caries superficial

Figure 4. Pre-processed X-ray image with indication of caries superficial

In Fig. 5 and Fig. 6 the original and pre-processed X-ray images with indication of caries media are given.

Figure 5. Original X-ray image with indication of caries media

Figure 6. Pre-processed X-ray image with indication of caries media

The same pre-processed X-ray image, but in the presence of caries profunda is shown in Fig. 7.

Figure 7. Pre-processed X-ray image with indication of caries profunda

We then apply split and merge segmentation to better visualize selected ROI images with these 3 types of caries. In Fig. 8 the selected ROI image with indication of caries superficial and its modification after segmentation is given.

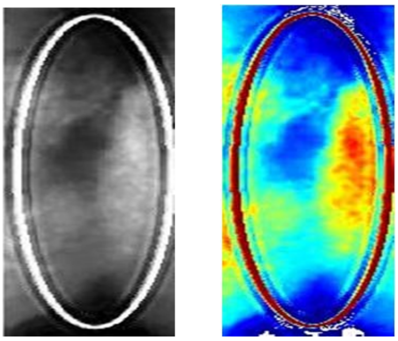

Figure 8. ROI image with caries superficial and its segmented modification

The selected ROI image with indication of caries media and its modification after segmentation is presented in Fig. 9.

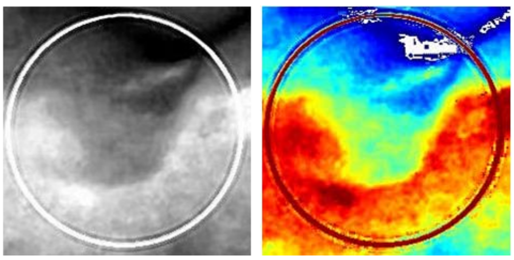

Figure 9. ROI image with caries media and its segmented modification

The indications of caries profunda in the selected ROI image and in its segmented modification are given in Fig.10.

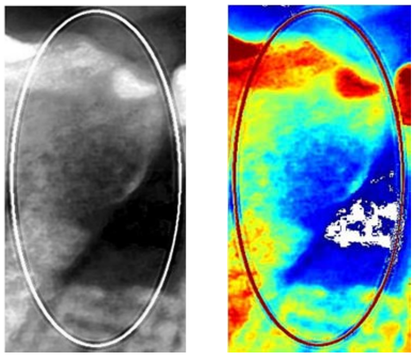

Figure 10. ROI image with indication of caries profunda and its segmented modification

We compare our experimental results with results, which are obtained by other methods for X-ray image enhancement and noise reduction, based on histogram equalization (HE), CLAHE and wavelet discrete transform (DWT) [17,18]. Table 2 contains the averaged simulation results by following methods: HE, following by morphological processing and noise reduction, based on WP transform (HE+MF+WPT); CLAHE, MF and noise reduction by homomorphic filter, based on DWT (CLAHE+MF+DWT). The compared results show, that the best results for image improvement are obtained by the proposed approach.

Table 2. Simulation results, obtained by different methods for dental image enhancement

Methods of processing	PSNR [dB]	SNR_f [dB]	SNR_g [dB]	E_{FF} [dB]
HE+MF+WPT	26.397	10.235	11.014	0.779
CLAHE+MF+DWT	27.586	10.235	12.280	2.045
Proposed method	29.284	10.235	13.594	3.359

These results have indicated that the application of the pre-processing stage visually increases the accuracy of observation the area of enamel destruction. The segmentation of the selected area can help the dentist to obtain more information about the progress of the carious process of tissue involvement-based caries.

4. CONCLUSION

In this paper, an effective approach for X-ray image processing of tissue involvement-based caries detection is proposed. The pre-processing stage, based on contrast enhancement and noise suppression based on modified homomorphic wavelet filter is first provided. For better visual observation of the detected caries, the split and merge segmentation of selected ROI images with different type of carries is applied. The segmented area can give more information about the depth of the structural defect and the progress of the carious process.

The proposed approach can be applied for screening of early detected caries or in monitoring the disease progression. The obtained image database of detected caries can be easily used for classification, based on different classification systems.

5. ACKNOWLEDGMENTS

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