Orthodontics Objects Segmentation Using Region Growing Method and Space Illumination

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Abstract: The paper presents a new method for enhancement of orthodontic images using the combination of two-dimensional data with different type of illumination and their processing using digital de-nosing and gradient image enhancement in the preliminary stage. The region growing method and the appropriate seed selection is then studied as an alternative to the distance and watershed transforms for their segmentation. The main goal of the paper is in (i) the presentation of mathematical methods for image analysis in the orthodontic treatment and (ii) presentation of the region growing method use for image regions classification. Resulting algorithms are used for gradient edge detection and image components enhancement in orthodontics.

Key–Words: Biomedical image processing, object illumination, digital filters, gradient methods, image segmentation, region growing method

1 Introduction

The digital analysis of multi-dimensional objects forms an important area of signal processing with various applications in engineering, biomedicine, environmental engineering and further areas. General image processing methods can be applied to digital photos, three-dimensional data resulting from computer tomography or multi-dimensional object scanning in more complex cases.

The paper is devoted to analysis of digital photos of plaster casts in orthodontics [4, 20, 5] with different illumination sources to analyse situation during the orthodontic treatment. Two images with the left hand side and the right hand side form the fundamental source of information. Both these images are divided by the vertical axes in the selected (central) fixed point and then combined to obtain images presented in Figs 1 and 2. Image A in Fig. 1 stands in this way for the central illumination and image B in Fig. 2 represents the side illumination. These images are then analysed to study the time evolution of dental arch during the orthodontic treatment [19, 17] for the following segmentation and the three-dimensional modelling.

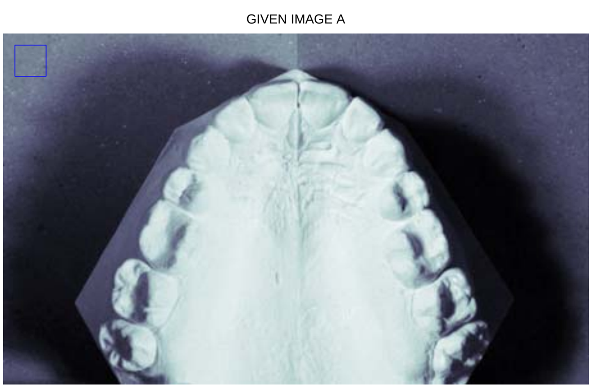

Figure 1: Image A combined from two outer parts of individual side illuminated plaster casts

Figure 2: Image B combined from two inner parts of individual side illuminated plaster casts

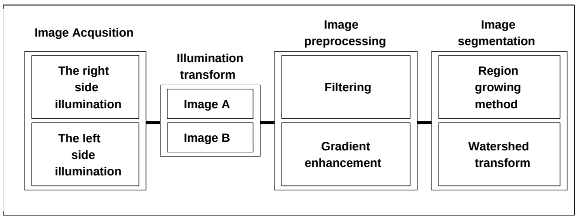

Figure 3: Block diagram of the proposed method for orthodontic image processing and segmentation

To enhance the image the digital filtering and gradient methods are used in the preprocessing stage followed by image segmentation according to block diagram in Fig. 3. Mathematical problems related to such an image processing include problems of their de-nosing [18, 10], image enhancement [1, 14], their segmentation and detection of specific objects using different transforms and morphological operations [8, 15] and segmentation techniques [11, 2, 7, 3].

2 Orthodontic Modelling

It is very important in orthodontics and prosthodontics to be able to compare dimensions of dental arch, position of teeth and groups of teeth before, during and especially after the treatment. Orthodontic modelling forms an important area in the dental care. New prosthodontic methods, including implant insertion, can be instituted using therapy by the surgeon, orthodontist and prosthodontist [16].

Dental casts are golden standard in the diagnosis and treatment planning in various fields of dentistry but have some disadvantages, too. Not only they require spacious storage areas, but it is also difficult to share them with other specialists when planning the treatment. Gypsum as the basic material of plaster casts is a fragile material and can be broken during the transport.

Nowadays we are trying to digitalize plaster casts and analyze them to use the results in specific area detection, enhancement and classification. Replacement of plaster casts by appropriate digital models can be advantageous allowing sharing the models with other specialists needed during the therapy and giving the possibility of accurate measurements and use of diagnosis setups.

3 Image Preprocessing

Image preprocessing include the analysis of image noise components at first to suggest appropriate digital filter to decrease its affect to image enhancement. Fig. 4 presents histograms of such a noise in the selected region of Fig. 1 before and after its rejection by the moving average and median filtering.

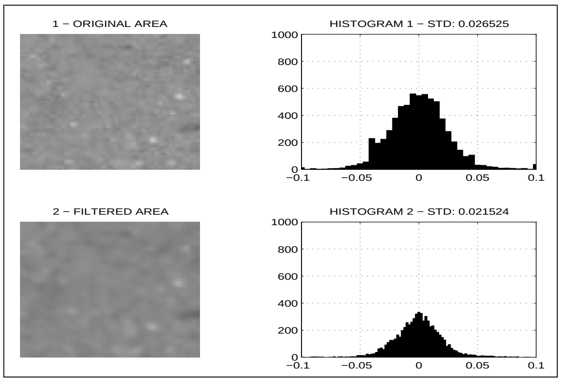

Figure 4: Noise analysis before and after filtration

Results of the following gradient enhancement of images in Figs 1 and 2 with different illumination are presented in Fig. 5(a) and (b). Fig. 5(c) presents how combination of these individual results can increase the quality of this process.

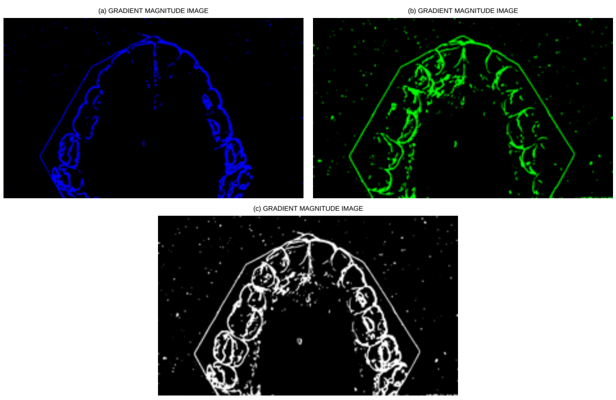

Figure 5: Edge detection for different illumination sources presenting the use of gradient method (a) to image A, (b) to image B, and (c) their combination

4 Image Segmentation

There are many different possibilities of image regions segmentation [9] and we shall study the use of the watershed and region growing methods for processing of orthodontic images only.

4.1 Watershed Transform

The watershed transform of an image matrix $\mathbf{A}_{M,N} = \{a_{i,j}\}_{i-1}^{M}\,{}_{j=1}^{N}$ related to image $F = f(x, y)$ with a selected resolution $M\ x\ N$ is a commonly used tool for image segmentation [9]. Its principle is based upon the analogy with the description of the ground surface in geography as it detects the ridge lines that divide areas drained by different river systems into separate catchment basins or reservoirs. This concept is used for processing of gray-scale images to overcome a variety of the segmentation problems. Algorithms using this principle take into account a gray-scale image as a topological surface, where the values of $f(x, y)$ are interpreted as heights. The watershed transform then finds the catchment basins and ridge lines separating this areas. Resulting catchment basins are objects or regions we want to identify [9] during this segmentation process.

The evaluation of the watershed transform is closely related to the distance transform used for processing on a binary (white & black) image [7, 9]. To apply watershed transform with distance transform, it is necessary to convert the gray-scale image to binary image calculating global image thresholds using the Otsu's method [9]. The Euclidean distance is then evaluated as a distance from each pixel to the nearest nonzero-valued pixel. This principle is illustrated below for the 4×4 matrix of zeros and ones that is firstly described as the binary image with the distance transform evaluation.

0	0	0	0
0	1	1	0
0	1	1	0
0	0	0	0

$(a)\ Binary\ image$

1.41	1.00	1.00	1.41
1.00	0.00	0.00	1.00
1.00	0.00	0.00	1.00
1.41	1.00	1.00	1.41

$(a)\ Distance\ transform$

After the evaluation of the distance transform the watershed transform is applied. Resulting labelled matrix has zero values corresponding to watershed ridge pixels and the positive integer values implying catchment basins [9]. The proposed method is summarized in algorithm A.

Algorithm A: Watershed segmentation

1. Image conversion to the grayscale
2. Image preprocessing (linear or nonlinear filtering and intensity adjustment)
3. Conversion of the grayscale image to binary image by the Otsu's method
4. Computation of the distance transform of complement of the binary image
5. Calculation of the watershed transform

The common problem of the watershed-based segmentation method is the problem of oversegmentation and improper split of some objects [9]. This situation occurs in complicated orthodontic image processing as well and further modifications of this method must be applied.

The gradient magnitude is often used to preprocess a gray-scale image before the application of the watershed transform. Having a grayscale image $F = f(x, y)$ then its gradient is defined by the column vector

$$\nabla F = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix}^T \tag{1}$$

The gradient magnitude and its direction are given by relations

$$Image_{mag} = \sqrt{(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2} \tag{2}$$

$$Image_{dir} = tan^{-1}\left(\frac{\partial f}{\partial y} \ / \ \frac{\partial f}{\partial x}\right) \tag{3}$$

Evaluating the gradient magnitude image it is possible to emphasize pixel values along object edges and to decrease intensity values of pixels in other locations [9]. Gradient magnitude can be used in this way as edge indicator in both image directions in order to identify region boundaries using linear filtering methods [7]. Sobel edge detector is one of edge filters that emphasizes edges of image in both vertical and horizontal directions [9].

After the evaluation of the gradient magnitude of the image the watershed transform is used to detect its local minima as catchment basins with their edges standing for the watershed segmentation. The problem of oversegmentation can be reduced by the appropriate image preprocessing and gradient smoothing [9] as well. The principle of this kind of segmentation is described in algorithm B.

Algorithm B: Gradient in watershed transform

1. Image conversion to the grayscale
2. Image filtering to reduce the noise
3. Gradient image enhancement and its smoothing to reduce oversegmentation
4. Computation of the watershed transform

4.2 Region Based Technique

Region-based technique is another widely studied method of segmentation that is based on the direct detection of regions [2, 9, 13] using properties of image pixels and their distribution. Owing to this idea specific preprocessing techniques are required in most cases to obtain more reliable results. The region-based method group pixels into regions taking into account the neighborhood of each pixel according to selected properties and pre-defined similarity criteria including texture, brightness and color or grey level of individual elements. Pixels having similar properties form a region and are joined together [2].

Let $\mathbf{A}$ denotes the whole image matrix under the study. The process of image segmentation can be then defined by partitioning of the whole image $\mathbf{A}$ into Q connected sub-regions $\mathbf{R_1}, \mathbf{R_2}, ..., \mathbf{R_Q}$ covering the whole image which means that

1. $\bigcup_{k=1}^{Q} \mathbf{R_k} = \mathbf{A}$
2. $\mathbf{R_k} \bigcap \mathbf{R_l} = \emptyset$ for all $k \neq l$

The efficiency of the region-growing method depends upon the appropriate selection of initial seeds. In case of the a priory information about image properties such starting points can be defined directly. In the other case selected properties should be evaluated for each pixel and after the initial clustering process seeds can be be defined in centroids of clusters obtained. Starting from initial seed points and using predefined criteria it is possible to group pixels into larger regions adding the neighboring pixels with similar properties.

The iteration process of the region-growing method can be stopped in case that all pixels are distributed into regions according to predefined criteria but some additional conditions can be added like region sizes or shape. According to selected threshold values and the sensitivity the extracted region may grow over the actual region boundary [6]. The suitable selection of seed points, stoping rules, thresholding and sensitivity [11] are very important for the efficiency of the whole process. The region-growing techniques are generally better for noisy images, where borders are extremely difficult to detect.

Fig. 6 presents results of the region growing of a simulated image allowing a very simple segmentation of a selected geometrical shape. The principle of segmentation is described in algorithm C.

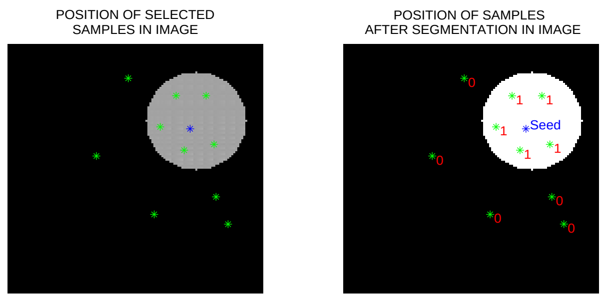

Figure 6: Principle of the region growing method and its application for a simulated image

Algorithm C: Region growing

1. Conversion of the original image to the grayscale image
2. Image filtering and intensity adjustment to improve the segmentation process
3. Selection of the arbitrary seed pixel and comparison of its selected properties with neighbouring pixels
4. Estimation of the threshold by considering the image histogram
5. Application of the region-growing around the arbitrary seed pixel by adding neighbouring pixels with similar properties
6. The comparison of the difference between the original seed pixel and its neighbouring pixels properties with the selected threshold and application of the stopping criteria

5 Results

Fig. 7 presents the application of the watershed transform to an orthodontic subimage defined in Fig. 7(a) and over-segmented result which can be reduced by the following morhological operations [12].

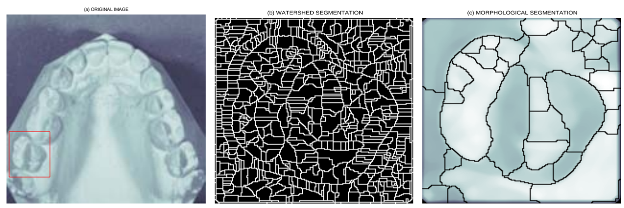

Figure 7: Orthodontic image segmentation presenting (a) the subimage selection, (b) watershed transform applied to subimage and resulting over-segmentation, and (c) results of morphological operations decreasing the over-segmentation

Results of the image segmentation and enhancement of the same subimage with the combined illumination are presented in Fig. 8. In comparison with the watershed transform of such a complicated area the region growing method is not so sensitive to over-segmentation.

Fig. 9 presents final results of image enhancement combining acquired image combination and region-growing method results.

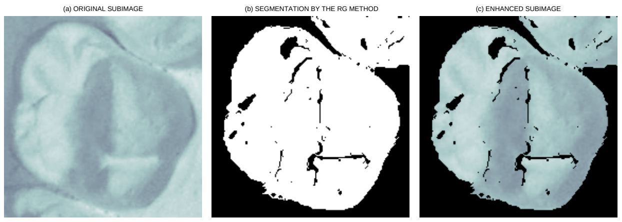

Figure 8: Subimage segmentation presenting (a) the original image, (b) segmentation results using the region-growing method, and (c) combination of both images

6 Conclusion

The paper describes the analysis of different segmentation methods applied to orthodontic images. Segmentation by distance and watershed transforms applied to the original or gradient magnitude image can cause problems of related to oversegmentation and detection of overlapping objects in case of more complex objects studied in orthodontics. The paper presents improved results obtained by image preprocessing using appropriate object illumination, its filtering and application of the region growing method.

Further studies will be devoted to more complex methods of orthodontic objects separation, segmentation and recognition to follow spacial changes during the orthodontic treatment.

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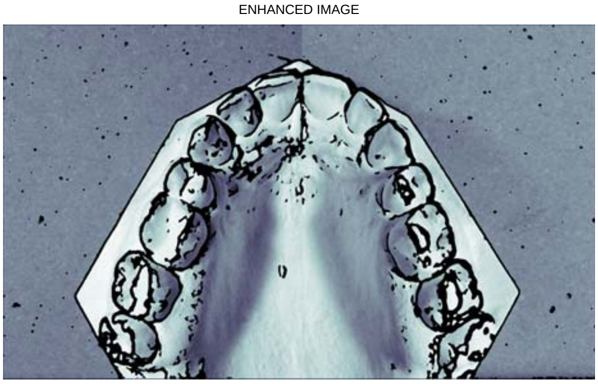

Figure 9: Final segmentation results and enhanced image using the region-growing method

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