Region Growing Method in Separation of Orthodontic Bodies Using Illuminated Models

Mohammadreza Yadollahi, Aleš Procházka, Martina Mudrová, Magdaléna Kašparová, Taťjana Dostálová

***Abstract*—**The paper presents a new method for detection of orthodontic bodies, their separation, enhancement and analysis using their plaster casts models illuminated by different light sources. The proposed method is based upon the processing of the set of two-dimensional images acquired in different illumination conditions using digital de-nosing and gradient image enhancement methods in the preliminary stage. The region growing method forms the main part of the paper with its results compared to the distance and watershed transforms. Mathematical methods studied include (i) selected computational tools for multi-dimensional analysis in the orthodontic treatment and (ii) segmentation methods based upon illuminated objects allowing the application of the region growing method for image regions classification The proposed set of algorithms is then used for orthodontic bodies segmentation and for comparison of results achieved. All methods are applied in orthodontics for segmentation of specifie objects to allow the efficien treatment and to simplify the organization of further analysis of treatment results in the electronic form accessible for all specialists in the given area.

***Key-Words*—**Biomedical signal processing, digital filters gradient methods, image segmentation, multi-dimensional objects analysis, object illumination, orthodontics, region growing method

I. Introduction

DIGITAL modelling and computational intelligence applied to numerical analysis of multi-dimensional objects form important interdisciplinary topics of signal processing with various applications in engineering, biomedicine, environmental engineering and further areas. General image processing methods can be applied to processing of digital two-dimensional records or multi-dimensional data resulting from computer tomography and object scans in more complex cases. In the past, computer technology as a monitoring and diagnostics tool in the treatment of patient in dental medicine was limited. Application of computer science and available digital technologies, such as digital data acquisition, virtual models study, computed tomography, video image processing, etc., considerably [1] improve the quality of data analysis for diagnostics and treatment of orthodontic patients.

The paper is devoted to analysis of digital images of plaster casts in orthodontics [2], [3], [4] with different illumination sources to analyse progress of the orthodontic treatment and to compare the situation before and after operations. Two images

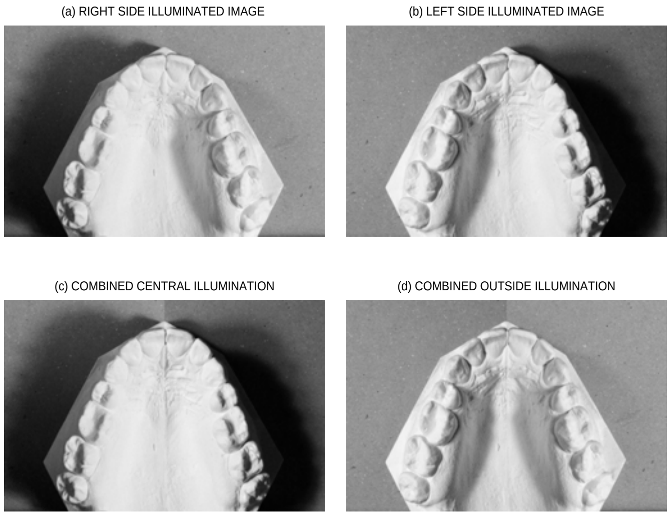

Fig. 1. The orthodontic plaster cast image presenting the model using (a) the right side and (b) the left side illumination used for combined images based upon (c) two outer parts images, and (d) two inner parts images using selected components of original data and appropriate combination of image pixels

with the left hand side illumination and the right hand side illumination in Fig. 1(a) and (b) form the fundamental source of information. Both these images are divided by the vertical axes in the selected (central) fi ed point and then combined to obtain images presented in Figs 1(c) and (d). Image presented in Fig. 1(c) stands in this way for the central illumination and image in Fig. 1(d) represents the side illumination. These images are then analysed to study the time evolution of dental arch during the orthodontic treatment [5], [6] using their digital processing, segmentation techniques and their three-dimensional modelling.

To enhance the image the digital filterin and gradient methods are used in the preprocessing stage followed by image segmentation according to block diagram in Fig. 2.

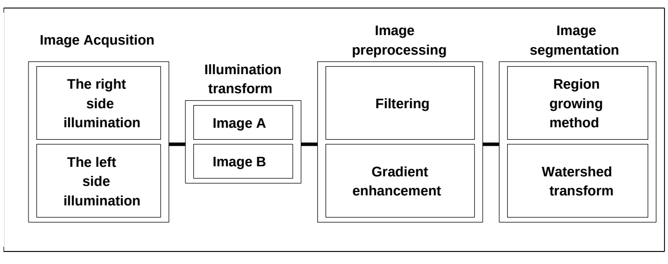

Fig. 2. Block diagram of the proposed method for orthodontic image processing and segmentation

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Mathematical problems related to such an image processing include problems of their de-nosing [7], [8], image enhancement [9], [10], location of specifi objects and detection of their edges using different transforms and morphological operations [11], [12] for their feature extraction, segmentation and classificatio [13], [14], [15], [16], [17].

II. Orthodontic Modelling

Digital modelling in two (2D) and three (3D) dimensions become widely used in many areas of medicine and dentistry [18], [19], [20] using different imaging technologies. The static nature of such models can be further improved by the study of their time evolution using different registration methods and selected regions of interests.

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 [21].

Dental casts are golden standard in the diagnosis and treatment planning in various field of dentistry but have some disadvantages, too. Not only they require spacious storage areas, but it is also difficul 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 specifi 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. A comparison of reproducibility and accuracy [22] of digital models are studied in this connection as well.

III. Image Preprocessing

Separating object out of its background and the creation and application of the mask on images can be useful in the initial image processing stage. The design of the binary mask is performed by the Otsu's thresholding method on the top hand side illumination of the original image. Otsu's method is a tool of segmentation in image processing with its performance based on the evaluation of variances between foreground and background pixels and the selection of the suitable threshold value by minimizing the intra-class variance or maximizing the inter-class variance [23]. Assuming an image consists of Q gray levels the probability [24] of gray level j is presented by

$$P_j = \frac{m_j}{M} \quad , \quad P_j \geq 0 \quad , \quad \sum_{0}^{Q-1} P_j = 1 \tag{1}$$

where (P, M, m) denote the probability, total number of pixels and the number of pixels respectively.

The pixels of the image in the bi-level thresholding method are categorized into classes by threshold T. The gray level probability distributions are

$$\omega_b = P_R(C_b) = \sum_{j=0}^{T} P_j \tag{2}$$

$$\omega_f = P_R(C_f) = \sum_{j=T+1}^{Q-1} P_j \tag{3}$$

where P_R presents the gray level probability distributions and (C_b, C_f) represent two classes of the image with different gray levels.

The means of class C_b and C_f are

$$\mu_b = \sum_{j=0}^{T} j \, \frac{P_j}{\omega_b} \tag{4}$$

$$\mu_f = \sum_{j=T+1}^{Q-1} j \, \frac{P_j}{\omega_f} \tag{5}$$

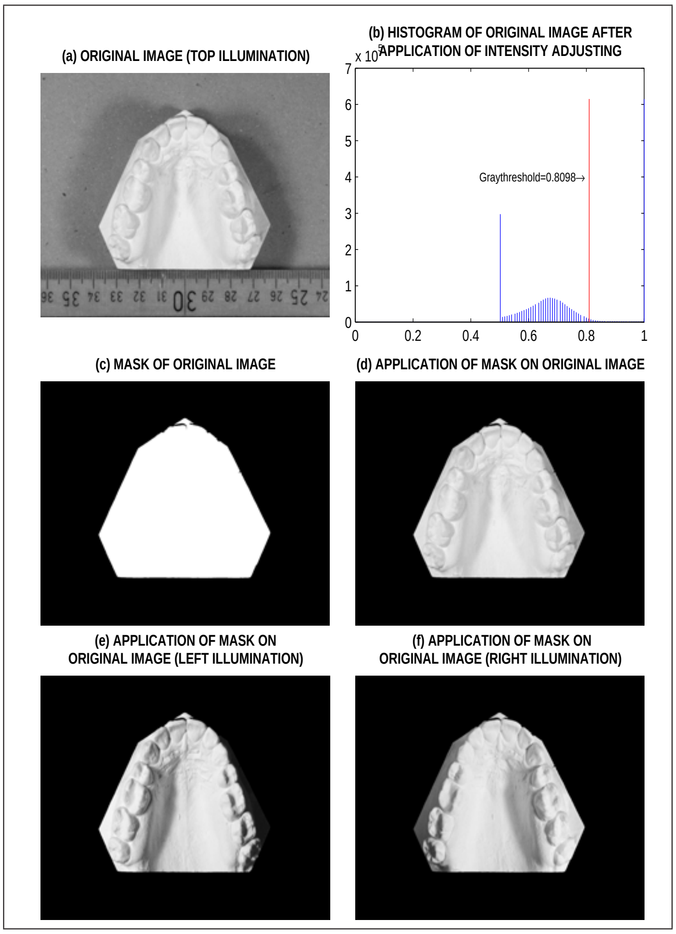

Fig. 3. The process of creation the mask presenting (a) the original image (top hand side illumination), (b) histogram of original image after application of intensity adjusting, (c) extracted mask, (d) application of the mask on the original image, and (e), (f) application of the mask for the left and right hand sides illuminations respectively

The class variances are

$$\sigma_b^2 = \sum_{j=0}^{T} (j - \mu_b)^2 \ \frac{P_j}{\omega_b} \quad (6)$$

$$\sigma_f^2 = \sum_{j=T+1}^{Q-1} (j - \mu_f)^2 \ \frac{P_j}{\omega_f} \quad (7)$$

Intra (within)-class variance is define by relation

$$\sigma_w^2(T) = \omega_b(T)\sigma_b^2(T) + \omega_f(T)\sigma_f^2(T) \quad (8)$$

and inter (between)-class variance can be evaluated by relation

$$\sigma_b^2(T) = \sigma^2 - \sigma_w^2(T) = \omega_b(T)\omega_f(T)\left[\mu_b(T) - \mu_f(T)\right]^2 \quad (9)$$

Fig. 3 presents mask extraction of top hand side illumination of original image by application of intensity adjusting and Otsu's method and finall employing the same mask on the left and right hand side illumination of the original image.

Image preprocessing includes the analysis of image noise components at firs to suggest appropriate digital filte to decrease its affect to image enhancement. Median filte is one of the most effective digital filter in suppression of impulsive noise in the image. It can decrease the image noise without blurring sharp edges because the median filte replaces the value of one pixel with the median value of all pixels in its neighborhood [25]. 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

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

IV. Image Segmentation

There are many different possibilities of image regions segmentation [26] and we shall study the use of the watershed and region growing methods for processing of orthodontic images only.

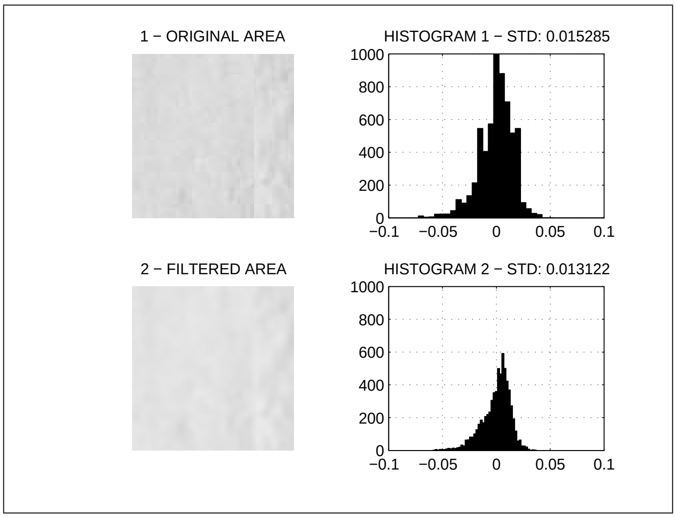

Fig. 4.   Noise analysis before and after filtratio   for a selected object region

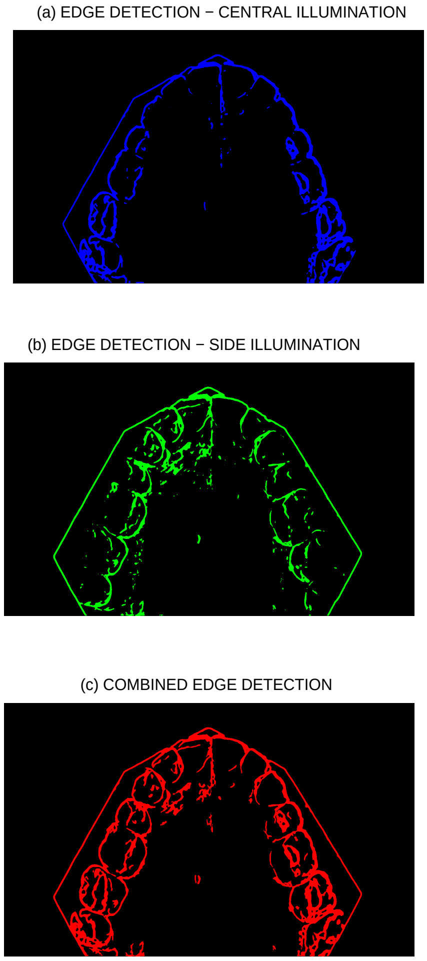

Fig. 5.   Edge detection for different illumination sources presenting (a) the use of gradient method to the combined image with central illumination, (b) results obtained for the outside illumination, and (c) addition of previous results

A. *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 [26]. 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 find the catchment basins and ridge lines separating this areas. Resulting catchment basins are objects or regions we want to identify [26] 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 [15], [26]. 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 [26]. 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 firstl described as the binary image with the distance transform evaluation.

(a) Binary image				(b) Distance transform			
0	0	0	0	1.41	1.00	1.00	1.41
0	1	1	0	1.00	0.00	0.00	1.00
0	1	1	0	1.00	0.00	0.00	1.00
0	0	0	0	1.41	1.00	1.00	1.41

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 [26]. The proposed method is summarized in algorithm A.

Algorithm A: Watershed segmentation
1) Image conversion to the grayscale
2) Image preprocessing (linear or nonlinear filterin 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 over-segmentation and improper split of some objects [26]. This situation occurs in complicated orthodontic image processing as well and further modification of this method must be applied.

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

$$\nabla F = \begin{bmatrix} \frac{\partial f}{\partial x} & \frac{\partial f}{\partial y} \end{bmatrix}^T \tag{10}$$

The gradient magnitude and its direction are given by relations

$$Image_{mag} = \sqrt{(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2} \tag{11}$$

$$Image_{dir} = tan^{-1}\left(\frac{\partial f}{\partial y} \;/\; \frac{\partial f}{\partial x}\right) \tag{12}$$

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 [26]. Gradient magnitude can be used in this way as edge indicator in both image directions in order to identify region boundaries using linear filterin methods [15]. Sobel edge detector is one of edge filter that emphasizes edges of image in both vertical and horizontal directions [26].

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 [26] 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 filterin to reduce the noise
3) Gradient image enhancement and its smoothing to reduce oversegmentation
4) Computation of the watershed transform

B. Region Based Technique

Region-based technique is another widely studied method of segmentation that is based on the direct detection of regions [14], [26], [27] using properties of image pixels and their distribution. Owing to this idea specifi 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-define similarity criteria including texture, brightness and color or grey level of individual elements. Pixels having similar properties form a region and are joined together [14].

Let $\mathbf{A}$ denotes the whole image matrix under the study. The process of image segmentation can be then define by partitioning of the whole image $\mathbf{A}$ into Q connected subregions $\mathbf{R_1}, \mathbf{R_2}, ..., \mathbf{R_Q}$ 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 efficien y 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 define directly. In the other case selected properties should be evaluated for each pixel and after the initial clustering process seeds can be be define in centroids of clusters obtained. Starting from initial seed points and using predefine 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 predefine 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 [28]. The suitable selection of seed points, stoping rules, thresholding and sensitivity [13] are very important for the efficien y of the whole process. Where borders of the object are extremely difficul to detect, the result of segmentation by region growing is often very satisfactory [29].

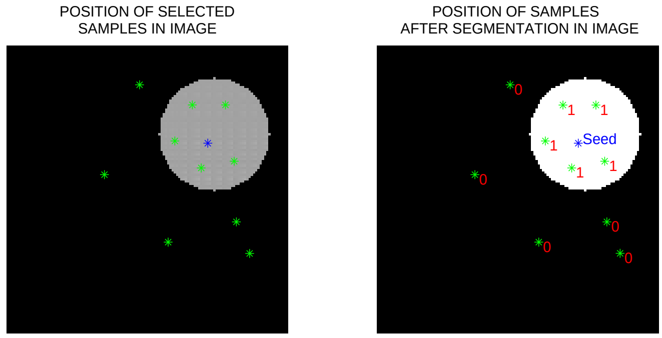

Fig. 6. Principle of the region growing method and its application for a simulated image

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.

Algorithm C: Region growing

1) Conversion of the original image to the grayscale image
2) Image filterin 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

V. Separating Two Objects in Region Based Technique

The separation of two objects whereas their common boundaries are removed during processes done on the image is an important issue in the image segmentation. The results of segmentation for two connected objects without middle boundaries are usually not satisfactory and the main challenge is caused by the situation when two objects segment as one. In this paper, it is described how to identify common boundaries of two objects. The firs step of this method is the application of mathematical morphology, such as dilation and fillin the holes in the binary image. Dilation aims to expand objects in a binary image. Magnitude of enlargement of objects is controlled [30], [31] by different shapes and values as structuring elements. The dilation of *I* by *SE* is define by

$$[I \bigoplus SE]_{(k,l)} = \bigcup_{\{SE[(k,l);(k,l)+(\delta_k,\delta_l)]=1\}} I[(k,l)-(\delta_k,\delta_l)] \tag{13}$$

where *I* is a binary image and *SE* denote a structuring element.

The second step of this method involves the application of boundary tracing of two objects. In the binary image, the foreground pixels are labelled as one and background pixels are labelled as zero so that in the boundary tracing the pixels of foreground are detected.

The third step is based on the calculation of column means and subtracting the column means from the corresponding columns of the labelled boundary. The arithmetic mean [32] is the average of a set of numbers evaluated by formula

$$AM = \frac{\sum_{i=1}^{N} x_i}{N} \tag{14}$$

where *AM* is the arithmetic mean, *N* is the number of samples and x_i is the value of each individual sample in the set of samples.

The forth step transforms data from the third step to polar coordinates. In the cartesian system, the axes are perpendicular to each other and a point in this system is determined by the length of this point to origin [33] in the x x y plane. In the polar coordinate system, this point is determined by an angle and a distance. The polar coordinates is calculated from cartesian coordinates by relation

$$\rho = \sqrt{x^2 + y^2} \tag{15}$$

$$\Theta = \tan^{-1}\left(\frac{y}{x}\right) \tag{16}$$

where ρ is the distance from the origin to the point, θ is counterclockwise angle relative to the x-axis, *x* and *y* are cartesian x-coordinate and cartesian y-coordinate respectively.

The fift step is the curve smoothing by moving average filte . The moving average filte is a common tool for smoothing sampled data forming a special case of the low-pass FIR (Finite Impulse Response) filte . It takes samples of data as input and calculates the average of them - output of this result in each single point. The formula of moving average filte is described [34] by relation

$$y(i) = \frac{1}{M} \sum_{j=0}^{M-1} x(i-j) \tag{17}$$

where $\{y(i)\}$ is the output data, $\{x(i-j)\}$ is the input data, and *M* is the number of points in the moving average filte .

The last step includes the evaluation of the local minima of the curve which will mark the position of intersection points of two objects. The local minima can be determined by two main methods, depending on the nature of data. The firs method is applied by curve fittin to defin a function, then by taking the firs and the second derivatives of this function to identify the local minima and maxima. However, this method does not always make it possible to defin the function. The proposed method applied in this paper is based upon the specifi algorithmic approach. The maximum peak is detected as maximum point, providing it has the maximal value and was preceded (to the left) by a value lower by special value (delta) [35] and the algorithm for minimum peak is reverse.

Fig. 7 presents all the processes that were explained in this section. The image assigned as Fig. 7(a) displays plaster casts image which shows a square area of the two objects for which segmentation is considered, Fig. 7(b),(c),(d) show cropping of original image for which segmentation is considered, application of region growing segmentation on cropped image, adding zero pixels to cropped image in order to extract boundary of whole object respectively. The set of images assigned as Fig. 7(e),(f),(g),(h),(i) describe the method of splitting two objects. Fig. 7(e) presents the procedure used to extract boundary of two objects of a region object by morphology methods (this step is supposed to produce a continuous and thin boundary), then tracing of extracted boundary. Fig. 7(f) presents the series of mathematical processes on tracing data boundary, transform to polar coordinates and using moving average filte to produce a smooth curve, Fig. 7(g) displays the position of intersection points in two objects based on the identifie local minima in Fig. 7(f). The result of fina segmentation and line separation between two objects is demonstrated in Fig. 7(h). The line separation in binary image is showen in Fig. 7(i).

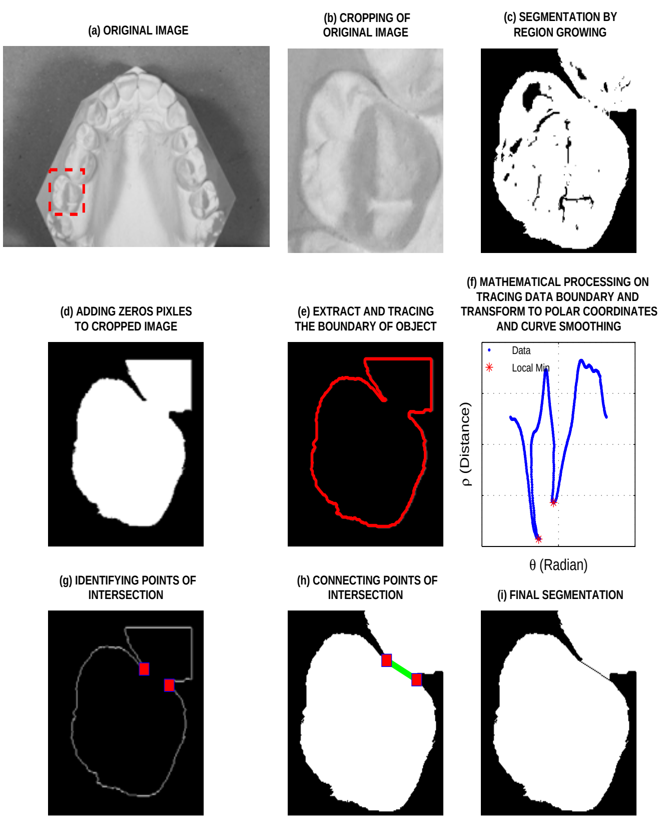

Fig. 7. Processing of identificatio common boundary between two objects, (a) displaying plaster casts, (b) selected area of two objects on plaster casts image, (c) application of region growing method on selected area, (d) adding zero pixels to cropped image, (e) extracting and tracing the edge of two objects, (f) mathematical processing on tracing data boundary and transform to polar coordinates and curve smoothing, (g) demonstrating of intersection points on two objects, (h) connecting intersection points of two object, (i) result of the fina segmentation on binary image

VI. Results

Fig. 8 presents the application of the watershed transform to an orthodontic subimage define in Fig. 8(a) and over-segmented result which can be reduced by the following morhological operations [36].

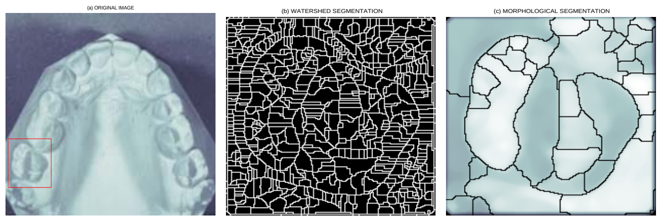

Fig. 8. Orthodontic image segmentation presenting (a) the subimage selection, (b) watershed transform applied to subimage and resulting over-segmentation, and (c) results of morphological operations decreasing the over-segmentation

Results of the image segmentation and enhancement of the same subimage with the combined illumination are presented in Fig. 9. In comparison with the watershed transform of such a complicated area the region growing method is not so sensitive to over-segmentation.

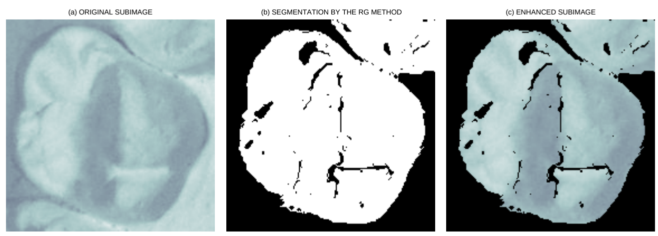

Fig. 9. Subimage segmentation presenting (a) the original image, (b) segmentation results using the region-growing method, and (c) combination of both images

Fig. 10 presents fina results of image enhancement combining acquired image combination and region-growing method results.

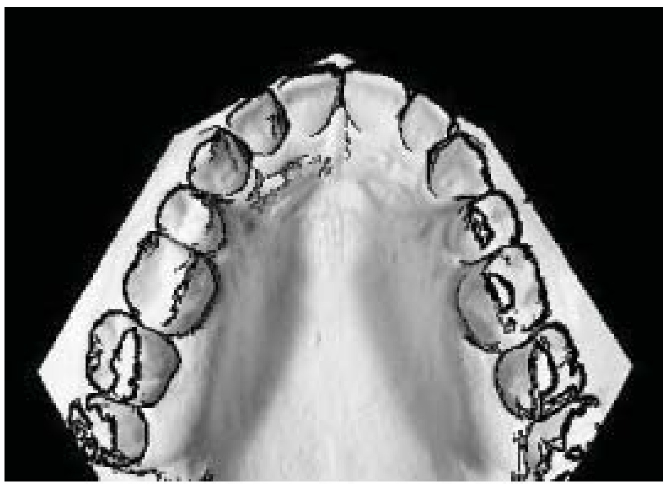

Fig. 10. Final segmentation results and enhanced image using the region-growing method

VII. 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 filterin 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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