Computer Aided Orthodontics Measures Evaluation

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Abstract: The paper is devoted to analysis of orthodontic images and to new mathematical methods for evaluation of their characteristics. The main goal of the paper is in analysis of three-dimensional objects to enable numerical evaluation of measures important for the study of the appropriate treatment after dental operations. Methods presented include (i) computer analysis of a single image based upon its de-noising followed by a thresholding and image components detection and (ii) presentation of tools for the three dimensional modelling using the double camera system. Proposed algorithms allow semi-automatic evaluation of measures between selected objects.

Key–Words: Biomedical image processing, segmentation, 3D object detection, geometric modelling, orthodontics

1 Introduction

The three-dimensional modelling forms an important area of multi-dimensional signal processing with applications both in static volume analysis and video processing. Methods used for these applications can be applied also for the study of evolution of the treatment in biomedical applications using observations recorded in selected time instants.

Mathematical problems related to a single biomedical image analysis [8, 15, 2, 10] include in many cases problems of its de-nosing [18, 9], image enhancement [1, 14, 13], its segmentation and detection of specific objects. Similar methods can then be used in the three-dimensional case [7] using multi-camera systems [12, 16, 17, 11] enabling to associate each object with its coordinates in the selected three-dimensional space. Having sets of such images in specific time instants its further possible to study the three-dimensional movement or evolution of specific objects in the biomedical case.

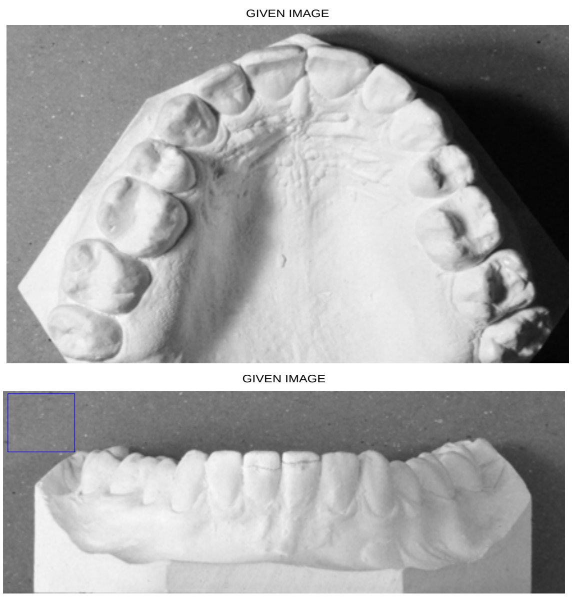

Figure 1: The top and front view of teeth to be analyzed with the background area used for noise study

The paper is restricted to biomedical applications and namely applications in orthodontics [3, 20, 4] to specify numerical measures between specified objects and to provide tools for repetition of this process to follow the success of the treatment after and operation [19, 6, 5]. Fig. 1 presents one of plaster casts used for such a computer analysis. In our study the time evolution of the dental arch width between canines (3-3) and second premolars (5-5) is studied.

2 Orthodontic Treatment Study

Dental casts play an important role in the diagnosis and treatment planning in prosthodontics and orthodontics and are golden standard in measuring dental arch distances and tooth position. Although there are many advantages of using dental plaster casts, replacement of plaster casts by digital models can be useful especially in saving space in storage areas, efficiency of having patient records accessible through computer, in possibility to share the models with other specialists needed during the therapy and possibility of accurate measurements and use of diagnosis setups.

In our case we have chosen set of plaster casts of patients with diagnosis of malocclusion (Class II in Angles classification), where extraction of first permanent premolars was part of the therapy. Therefore it is important to know how distances between tips of canines and contact points of second premolar and first molars change during the treatment. These points have not been chosen accidentally. Although the tips of canines can be seen as exact points on the top of incisal edge of canines, contact point of premolar and molar must be reconstructed by straight line going through intercuspidal line of premolar intercrossing distal edge of the premolar. This point is usually also contact point of premolar and molar. These facts are interesting for creating digital models of plaster casts and represent interesting matter for mathematical analysis.

3 Single Camera Use

Fig. 1 presents one of the orthodontic plaster cast used for evaluation of the distance between canines (3-3) with area used for the background noise study. This area together with noise histogram is presented in Fig. 2 before and after its rejection using the two-dimensional digital median filter.

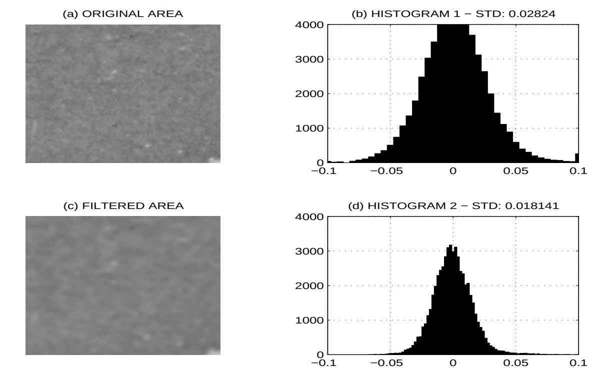

Figure 2: Analysis of the background noise presenting (a) the selected area, (b) its histogram, and (c), (d) the de-noised background area and its histogram

The gradient image enhancement and image thresholding is then applied to convert the figure of the plaster cast into its black and white form with results presented in Fig. 3 (a). Manually selected regions including canines are then used for automatic computational based detection of their extreme values according to Fig. 3 (b).

Knowing the camera resolution and the distance between image pixels it is then possible to evaluate the distance between canines with error given by image resolution. This result presented in Fig. 3 (b) as

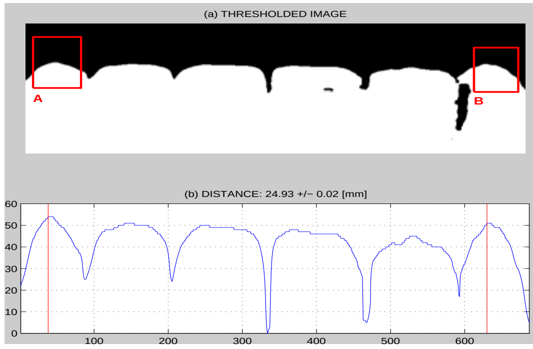

Figure 3: Evaluation of distances between canines presenting (a) thresholded image and selected regions for their extrema detection and (b) image contour plot and evaluation of the distance between given objects

well is precise enough in case that the plaster cast is perpendicular to the camera axis and object distance closely related to its physical resolution is properly defined.

4 Double Camera 3D Modelling

In case of more complex problems the three-dimensional modelling can be applied using the double camera system for data acquisition and for the precise detection of position of a selected object in the three-dimensional space. Fig. 4 presents the principle of the whole system arrangement using two cameras Dragonfly connected to the PC. The 6-pin 1394 standard cable provides the camera [12] with both power and a connection to computer having IEEE 1394 plug-in board. For transmission of images from cameras

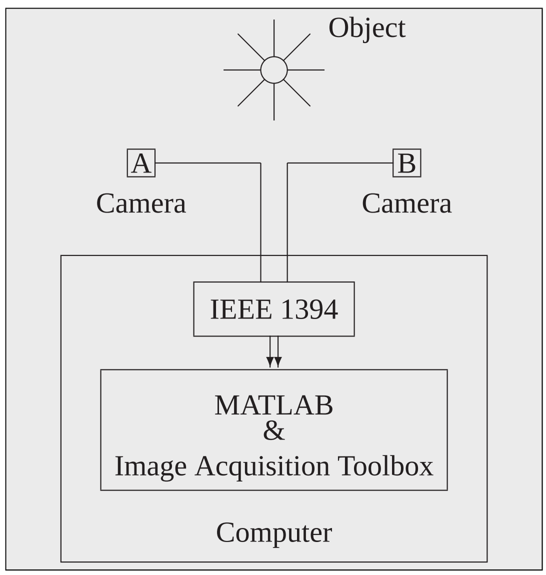

Figure 4: The two camera measurement system

to PC the MATLAB Image Acquisition Toolbox has been used to enable real time data processing.

In the more simple case it is possible to obtain images from separate cameras and to process them separately.

4.1 Calibration

The whole system presented in Fig. 5 consists of two cameras A and B located in the fixed distance c. The selected reference object C forms together with positions A and B a triangle that can be used for the definition of the three-dimensional coordinate system and for the following space detection of the specified bodies.

System calibration presented in Fig. 5 assumes known values of distances $a_1(0), b_1(0)$ and c of the triangle ABC. The cosine theorem can be then used to evaluate initial angles $\alpha_1(0)$ and $\beta_1(0)$ by relation

$$\alpha_1(0) = \arccos \frac{b_1(0)^2 + c^2 - a_1(0)^2}{2\ b_1(0)\ c} \tag{1}$$

$$\beta_1(0) = \arccos \frac{a_1(0)^2 + c^2 - b_1(0)^2}{2\ a_1(0)\ c} \tag{2}$$

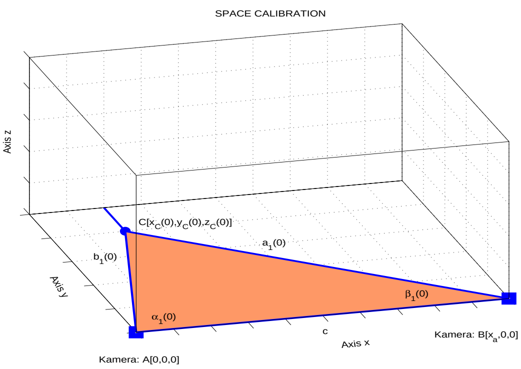

Figure 5: The definition of space coordinates using a fixed reference point C and the two camera system

In the following step it is necessary to evaluate horizontal and vertical angles of both cameras. Using the calibration grid table according to Fig. 6(a) placed in the distance d from camera A it is possible to find both horizontal $s_{horizontal}$ and vertical $s_{vertical}$ sizes of the figure. These parameters can then be used for evaluation of the limits of angles presented in Fig. 6(b) using rectangular red and blue triangles estimating in the case of camera A values

$$\alpha_{horizontal} = 2\ \arctan \frac{s_{horizontal}/2}{d} \tag{3}$$

$$\alpha_{vertical} = 2\ \arctan \frac{s_{vertical}/2}{d} \tag{4}$$

implying limits α_{1min}, α_{1max}, α_{2min} and α_{2max} using the initial point positioning and initial angles evaluated before. The similar process can be used for camera B. Knowing the number of pixels in both direction it is possible to find the angle resolution as well.

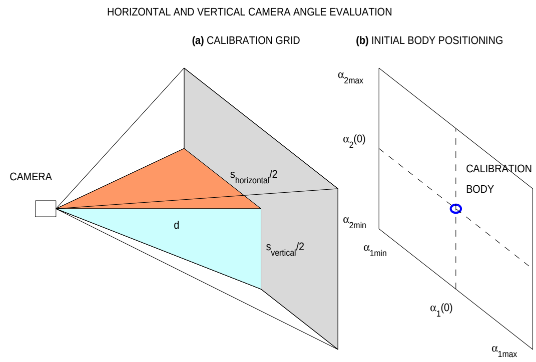

Figure 6: System calibration based upon (a) the use of the calibration grid table and (b) evaluation of horizontal and vertical camera angle limits

4.2 Observation

During the observation process the time-synchronized pictures taken by both cameras are acquired with results presented in Fig. 8. The situation for the k-th object step is given in Fig. 7. Objects specified either manually or by any algorithmic computational method can then be analyzed. Using the results of calibration given in Fig. 6 it is possible to convert the row and column positioning of each object to horizontal $\alpha_1(k)$ and vertical angles $\alpha_2(k)$ in the case of camera A and to $\beta_1(k)$ and $\beta_2(k)$ angles in the case of camera B.

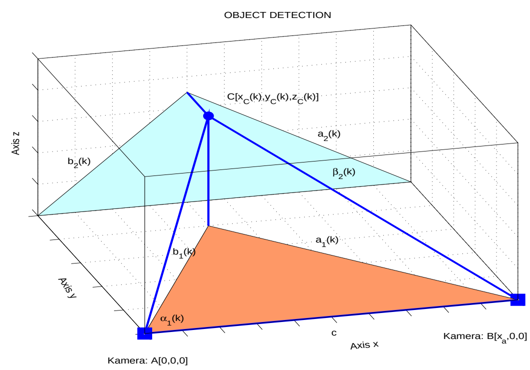

Figure 7: Two camera system allowing the space object localization

For the k-th object the set of two pictures is acquired defining triangle ABC in the space with the top and front view presented in Fig. 7. Using the system of coordinates with the origin in the position of camera A and choosing the axis x in the direction of camera B and y axis in the plane of the initial light positioning it is possible to evaluate coordinates of point

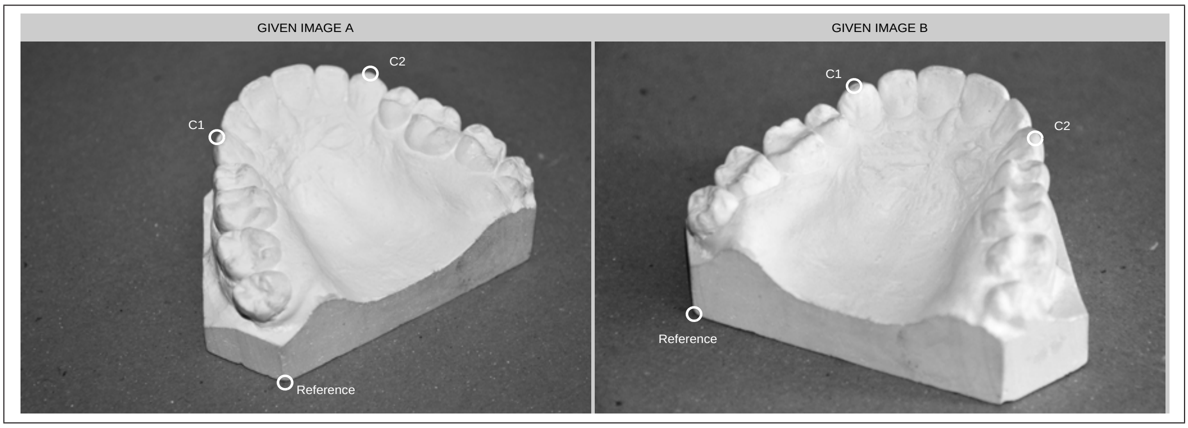

Figure 8: Plaster casts images observed simultaneously by two cameras in the distance of $c = 350mm$

C in the space. The top view enables to find the size of $b_1(k)$ using the sine theorem and coordinates of point C in the form

$$b_1(k) = c\ \sin(\beta_1(k))/\sin(\pi-\beta_1(k)-\alpha_1(k)) \quad (5)$$

$$x_C(k) = b_1(k)\ \cos(\alpha_1(k)) \quad (6)$$

$$y_C(k) = b_1(k)\ \sin(\alpha_1(k)) \quad (7)$$

The z coordinate of point C can be found in the similar way.

$$b_2(k) = c\ \sin(\beta_2(k))/\sin(\pi-\beta_2(k)-\alpha_2(k)) \quad (8)$$

$$z_C(k) = b_2(k)\ \sin(\alpha_2(k)) \quad (9)$$

Definition of the three-dimensional positioning of any body is given in this way in the chosen coordinate system from the set of two images.

To evaluate the distance between canines using the three-dimensional approach it is possible

- to detect specific points $C1$ and $C2$ belonging to canines from camera A according to principle described above for the single camera use
- to detect specific points $C1$ and $C2$ belonging to canines from camera B in the similar way
- to evaluate the distance between canines in the space using the three-dimensional coordinates of canines reference points by relation

$$D=\sqrt{(x_{C2}-x_{C1})^2 + (y_{C2}-y_{C1})^2 + (z_{C2}-z_{C1})^2} \quad (10)$$

Similar approach can be used for more complex numerical analysis of the space object as well.

5 Results

Fig. 8 presents plaster models observed by two cameras in the distance of $c = 350mm$ according to Fig. 7 with the reference point in the left corner and values $a_1(0) = 590mm$ and $b_1(0) = 430mm$.

After the calibration of both cameras and evaluation of their angular resolution it was possible to apply the whole algorithm. Specification of object components and numerical identification of the model allowed to obtain results presented in Fig. 9 with the value of the distance $Dist = 34.835mm$ obtained in the given case. Further numerical experiments and their comparison with the manual measuring proved the efficiency of the method suggested.

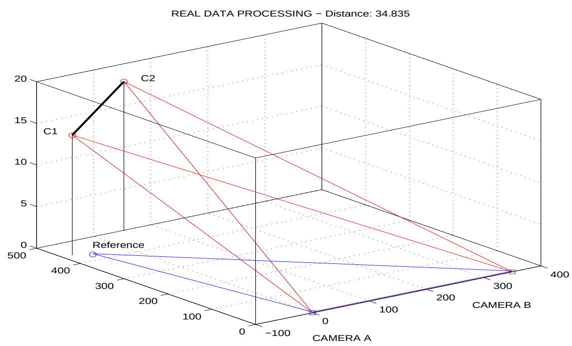

Figure 9: Visualization of the numerical processing of plaster casts using simultaneously observed data by two cameras in the distance of $c = 350mm$

6 Conclusion

The paper presents geometric modelling principles and their use in orthodontics to compare geometric distribution of teeth in the arch before and after the operation. The simple and more complex case based on the two camera system are compared.

The three-dimensional modelling approach can increase the accuracy of the measurement as the three-dimensional coordinates of specified points eliminate the inaccuracy of model positioning using one camera only. This advantage compensates for the more complex application of the two camera system.

Proposed algorithm in the MATLAB environment is general enough allowing analysis of three-dimensional models and the study of their time evolution as well. The method allows remote measuring using the images only. The following work will be devoted to more precise specification of measuring points and more complex multi-dimensional data processing.

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References:

[1] A. Procházka and J. Ptáček. Wavelet Transform Application in Biomedical Image Recovery and Enhancement. In *The 8th Multi-Conference Systemics, Cybernetics and Informatic, Orlando, USA*, volume 6, pages 82–87. IEEE, 2004.

[2] R. N. Bracewell. *Fourier Analysis and Imaging*. Kluwer Academic Press, 2003.

[3] Y. B. Chang, J. J. Xia, J. Gateno, Z. Xiong, X. Zhou, and S. T. C. Wong. An automatic and robust algorithm of reestablishment of digital dental occlusion. *IEEE Transaction on Medical Imaging*, 29(9):1652–1663, September 2010.

[4] J. Chapuis, A. Schramm, I. Pappas, W. Hallermann, K. Schwenzer-Zimmerer, F. Langlotz, and M. Caversaccio. A new system for computer-aided preoperative planning and intraoperative navigation during corrective jaw surgery. *IEEE Transaction on Information Technology in Biomedicine*, 11(3):274–287, May 2007.

[5] T. Dostalová, J. Racek, E. Lozeková, and M. Rerchová. Composite veneers, crowns, and inlay bridges after orthodontic therapy - a three-year prospective study. *General Dentistry*, 51:129–132, 2003.

[6] T. Dostalová, J. Racek, E. Tauferová, M. Seydlová, V. Smutný, and M Bartonová. Composite veneers, crowns, and inlay bridges after orthodontic therapy - a three-year prospective study. *Methods of Information in Medicine*, 45:191–194, 2006.

[7] J. L. Dugelay, A. Baskurt, and M.Daoudi. *3D Object Processing*. John Wiley & Sons, 2008.

[8] R. C. Gonzales, R. E. Woods, and S. L. Eddins. *Digital Image Processing Using MATLAB*. Prentice Hall, 2004.

[9] Onur G. Guleryuz. Iterated Denoising for Image Recovery. In *Data Compression Conference (DCC '02), Snao Bird, Utah*. IEEE, 2002.

[10] I. W. Selesnick and R. G. Baraniuk and N. G. Kingsbury. The Dual-Tree Complex Wavelet Transform. *IEEE Signal Processing Magazine*, 22, 2005.

[11] J. Lasenby and A. Stevenson. Using Geometric Algebra for Optical Motion Capture. In E.Bayro-Corrochano and G. Sobcyzk, editors, *Applied Clifford Algebras in Computer Science and Engineering*. Birkhauser, Boston, U.S.A., 2000.

[12] M. Kubíček. Using Dragonfly IEEE-1394 Digital Camera and Image Acquisition Toolbox. In *Technical Computing 2004*, pages 280–282. VŠCHT Praha, 2004.

[13] J. Kukal, D. Majerová, and A. Procházka. Dilation and erosion of gray images with spherical masks. In *The 15th Annual Conf. Technical Computing*, 2007.

[14] V. Musoko. *Biomedical Signal and Image Processing*. PhD thesis, Inst. of Chem. Technology, Prague, 2005.

[15] N.G. Kingsbury and J.F.A. Mugarey. Wavelet Transforms in Image Processing. In A. Procházka, J. Uhlíř, P. J. W. Rayner, and N. G. Kingsbury, editors, *Signal Analysis and Prediction*, Applied and Numerical Harmonic Analysis, chapter 2. Birkhauser, Boston, U.S.A., 1998.

[16] A. Procházka, M. Kubíček, and A. Pavelka. Multicamera Systems in the Moving Body Recognition. In *The 48th International Symposium ELMAR 2006*. IEEE, 2006.

[17] M. Ringer and J. Lasenby. Multiple Hypothesis Tracking for Automatic Optical Motion Capture. *Lecture Notes in Computer Science*, 2350, 2002.

[18] Saeed V. Vaseghi. *Advanced Digital Signal Processing and Noise Reduction*. Wiley & Teubner, West Sussex, U.K., second edition, 2000.

[19] K. Yamamoto, S. Hayashi, H. Nishikawa, S. Nakamura, and T. Mikami. Measurements of dental cast profile and three-dimensional tooth movement during orthodontic treatment. *IEEE Transaction on Biomedical Engineering*, 38(4):360–365, April 1991.

[20] M. Yaqi and L. Zhongke. Computer aided orthodontics treatment by virtual segmentation and adjustment. In *2010 International Conference on Image Analysis and Signal Processing (IASP)*, pages 336–339, April 2010.