FUZZY DETECTION OF CRANIOFACIAL LANDMARKS

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ABSTRACT

Accurate estimation of craniofacial landmarks highly increases efficiency and speed of diagnosis and treatment monitoring in orthodontics (1). Application of advance image processing techniques in recognition and detection of these features has been investigated here by implementation of a new method in pattern analysis. The major objective of the paper is to develop a suitable system including application of ISODATA pattern recognition technique together with a fuzzy logic decision making algorithm (2) in order to increase accuracy of the results. More than 96% accuracy is a brilliant achievement using the technique. The proposed procedure is preferred to previously introduced techniques for which low accuracy of the results when good quality images are used, has been reported.

1 INTRODUCTION

Cephalographs are lateral skull (craniofacial) X-radiographs. These images are highly used in orthodontics and jaw surgeries. Geometrical description of a set of points in hard and soft tissue projections provide necessary clinical information. Locating dominant landmarks and their geometrical description are the major objectives in cephalometry. Since plane X-ray images are usually very blurred, even recently orthodontic pathology has been often based on detection of craniofacial landmarks using Human Visual System (HVS) and manual geometrical measurements. Since popular manual methods are very time consuming process, automatic cephalometry has become of great importance. Manual technique can be replaced by Computerized methods only if a high degree of accuracy is achievable. Recently developed techniques in this area either are based on simple and inaccurate estimation of desired features or only special good quality images are selected for processing (3-9). In the methods proposed by almost all researchers the decision has been made based on extracted edge information. Obviously these methods fail for usual low contrast images. A knowledge base system was introduced by Levy-Mandel in order to reconstruct the edge map (6). In the procedure proposed by Cardillo and Sid-Ahmed (9), morphological operators are used for detection of most of the targets. In all above papers Low accuracy in estimation of the locations specially for low contrast images has been reported.

In this paper proper different-size two-dimensional masks are defined for different landmarks. By cross-correlating the enhanced image and the mask few candidates for the corresponding landmarks will satisfy maximum similarity condition. The landmark will then be accurately detected applying a Fuzzy decision making process.

2 CRANIOFACIAL PATTERN ANALYSIS

About 30 landmarks are depicted in the lateral skull profile of Figure 1. 12 of these features are of major importance (1). These features are Nasion, Sella Turcica, Tip of nose, Sub-nasal, Point A, Point B, Menton, Incisor Superiors, Gnathion, Maxillary plane, Mandibular plane, Occlusal plane, Porion and Orbitale. All above landmarks are successfully detected with very high accuracy.

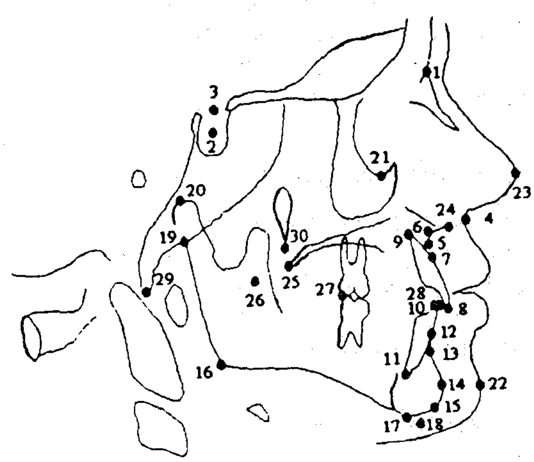


Figure 1; Location of landmarks

Suitable pre-processing algorithms have been applied for restoration and enhancement of the noisy data. In the following sections different steps in the proposed method are explained

2.1 Pre-processing of the cephalograph

The histogram of the image is divided into two parts, belonging to soft and hard tissues. Most of the processes are based on local data statistics. Application of side-information median filter (10) together with two-dimensional Gaussian filter effectively highlights the edges while reduces the high spatial frequency noise. In Figure 2 original image, The image when soft tissue is enhanced and the image when hard tissue is enhanced are illustrated. The edges have to be detected in order to enable accurate template matching in the vicinity of the features. Since the image is very noisy edge

a

b

c

Figure 2 a) Original image, b) Soft tissue enhanced, c) Hard tissue enhanced

detection based on gradient measurement such as sobol etc. does not work efficiently. The method applied here, fits two lines to the adjacent segments of each row or columns of the image. Assuming the lines to be $y1$ and $y2$ as:

$$y1=a1x+b1$$
$$y2=a2x+b2$$

Then a simple fuzzy decision making leads to detection of an edge;

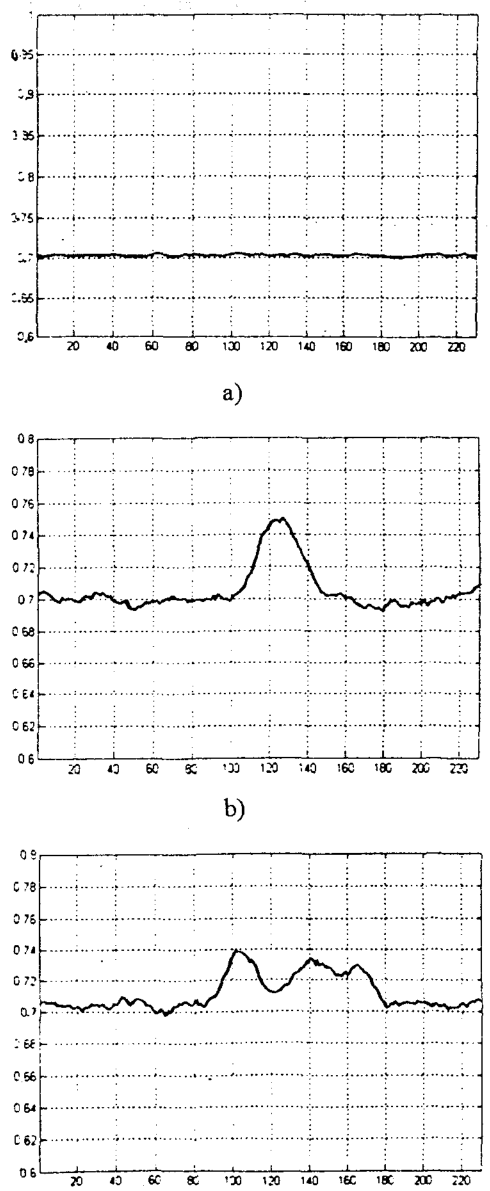
if a1 and a2 are different by a threshold or b1 and b2 are different when a1 and a2 are almost equal then an edge is detected.

2.2 Recognition of the Landmarks

Before all, a search area is estimated for each feature. These regions are determined based on primary knowledge about the organ, approximate location, type of tissue (soft or hard) and image statistics. The criterion decreases computation cost, simplifies the processor and increases the speed of computation. Proper matrices of suitable size are used as templates to match the selected candidates of the features. Definition of similarity functions using suitable window size for each feature (except Sella, Maxillary and Mandible planes) is considered to find maximum similarity between the landmarks and the selected templates. One dimensional cross-correlation is effectively used for this purpose. As an example, the function Z defined as

$$Z_i[j] = \frac{\sum_{l=-7}^{8} \sum_{m=-7}^{8} N1[l+7,m+7]*X[l+7,m+7]}{\sum_{l=0}^{15} \sum_{m=0}^{15} N1[l,m]^2 * \sum_{l=-7}^{8} \sum_{m=-7}^{8} X[i-l,j+m]^2}$$

determines cross correlation of a 16 by 16 square region centred at a point on the ith column of the image for detection of tip of nose. Letter j denotes jth pixel value of the ith column. The same Z is evaluated for values of i up to the point where the most matched points are detected. Figure 3 demonstrates three types of Z signals for noise, when tip of nose is detected and when part of nose plus tip of lips are detected, respectively.



a)

b)

c)

Figure 3; Z signals for a)noise b)when tip of nose included and c)when nose and tip of lips are included

Mean and Maximum of Z are calculated in order to define suitable threshold value each time, such as

$$Z_T = \frac{1}{3}(Z_{max} - Z_{mean}) + Z_{mean}$$

for determination of local maxima. A set of classes may be detected for above landmark. The method is based on Iterative Self Organizing Data Analysis (ISODATA) (11). A number of distinct groups of candidates is firstly recognized for each point. Winner group will then be one which has more candidates and also satisfies the anatomical conditions. A fuzzy table is then established based on the number of members for each class, location of the class and position of the next two classes belonged to tip of lips. When the right class is determined an smaller size template is used for further convergence to the point and finally detection of the landmark.

For locating Subnasal a local histogram equalisation together with using suitable threshold is required before template matching.

In detection of Incisor superious soft tissue is firstly eliminated by using an adaptive threshold. After detection of the closest candidates, dominant class is selected when it is closest to the right edge, is farthest from the top edge and the correlation value is maximum.

Maxillary and Mandible planes are nicely detected by application of a search algorithm started from Incisor Superiors followed by a clever detection of direction by LSF-based minimisation of Euclidean distances. In paediatric skull cephalograms, however, auxiliary planes are firstly defined in order to locate Maxillary and Mandible planes in the right positions. Occlusal plane will also be located after identification of above to planes.

Point A and point B are specified by proper interpolation of the planes, template matching and finally application of a fuzzy criterion.

In detection of sella turcica a number of familiar patterns are utilised as templates, to detect points, curves and corners in the vicinity of the landmark. Relative distances of the matched patterns are used as inputs to an already defined fuzzy system. the membership functions are practically extracted in order to cover all possibilities in shape of sella. The programme significantly converges to highlight accurate position of sella. Figure 4 shows suitable templates for detection of Sella turcica.

In detection of nasion, primary knowledge about position of sella is very advantageous. The search zone is within -20 to +20 degree relative to horizontal line started from sella.

$$Y2_{10*10} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 \\ 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 & 255 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$Y2_{10*10} = \begin{bmatrix} 0 & 0 & 0 & 0 & 255 & 255 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 255 & 255 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 255 & 255 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 255 & 255 & 0 & 0 & 0 & 0 \\ 255 & 255 & 255 & 255 & 255 & 0 & 0 & 0 & 0 & 0 \\ 255 & 255 & 255 & 255 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$Y3_{10*10} = \begin{bmatrix} 0 & 0 & 0 & 0 & 000 & 000 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 000 & 000 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 000 & 000 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 000 & 000 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 0 & 255 & 255 & 255 & 255 & 255 \\ 0 & 0 & 0 & 0 & 255 & 255 & 255 & 255 & 255 & 255 \\ 0 & 0 & 0 & 0 & 255 & 255 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 255 & 255 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 255 & 255 & 000 & 000 & 000 & 000 \\ 0 & 0 & 0 & 0 & 255 & 255 & 000 & 000 & 000 & 000 \end{bmatrix}$$

Figure 4; The templates for recognition of sella turcica

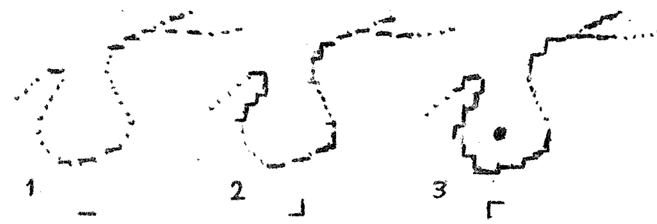


Figure 5; The steps for detection of sella Turcica

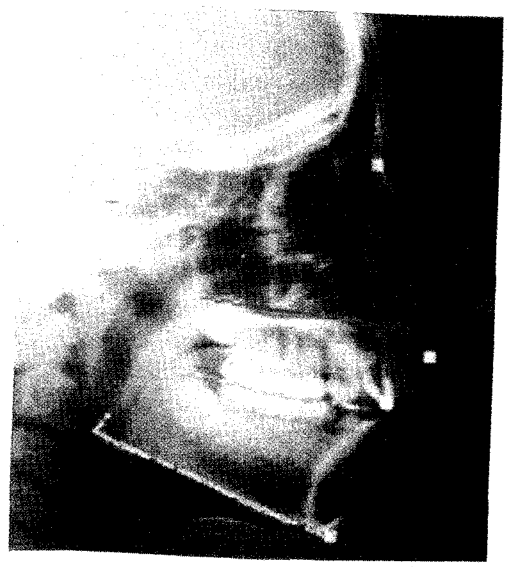


Figure 6; Detected Landmarks

Due to the nature of varying data for various skulls, a fuzzy decision making is required in order to verify relative possible positions of the landmarks.

Similar fuzzy criterion exploits relative geometrical positions and distances in accurate definition of the feature positions for different patients. All membership functions proportional to the similarity parameters are estimated using a large number of cephalograms derived from Iranian (white race) people. Figure 5 illustrates the steps in detection of sella and Figure 6 demonstrates detected landmarks for an arbitrary cephalogram.

CONCLUSION

More than 96% accuracy in average, with sufficient computation speed are considerable advantages of the proposed system over traditional automatic methods. The programme is executable over a wide range of data since the Fuzzy criteria exploits all shapes and geometrical description of the landmarks. The programme has possibility of manual operation, so it may also used for educational purposes.

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