Automated 2-D Cephalometric Analysis of X-ray by Image Registration Approach based on Least Square Approximator

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1 author:

I. El-Feghi

Misrata University

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Automated 2-D Cephalometric Analysis of X-ray by Image Registration Approach based on Least Square Approximator

I.El-Fegh*, M. Galhood**, M. Sid-Ahmed***, M. Ahmadi***
idrise@hii.edu.ly, MGalhoud@yahoo.com, ahmed@uwindsor.ca, ahamdi@uwindsor.ca,
* Higher Institute of Industry, Misurata-Libya, ** Al-Fateh University, EE Department, Tripoli-Libya,
*** University of Windsor, Windsor, Ontario, Canada

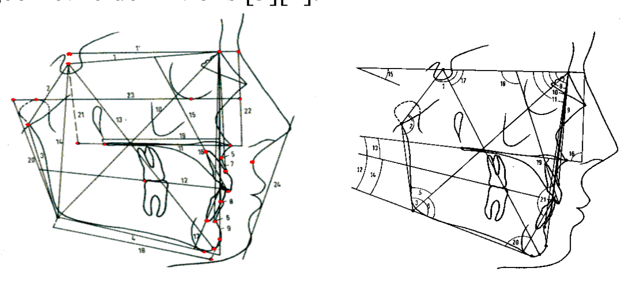
Abstract__ *This paper presents a new approach to cephalometric x-ray landmark localization. This approach is based on extracting features from face profile of the lateral skull x-ray. The extracted side profile is then segmented based on knowledge of known local facial structures. Once the face profile is properly segmented, nine perceptually significant landmarks (fiducial points) on the face are registered based on a local maximum curvature computation. These fiducial points are used for point-by-point correspondence to find the transformation coefficients of the control points between two images of a scene. Next, we use the obtained coefficients to find the locations of other landmarks on the target image by mapping the landmarks of the reference image. The algorithm was tested on more than 80 x-ray images to locate 20 landmarks. It was possible to locate the landmarks with accuracy of ±2mm on more 90% of the landmarks.*

I. INTRODUCTION

Cephalometric is defined as the scientific measurement of the human head, usually through the use of x-ray images of the lateral skull. This measurement is useful in many application in orthodontic for cephalometric evaluation, planning the treatment, or in obstetrics to gauge if a fetal head can pass through the birth canal [2]. The measurement is based on a set of agreed upon points called landmarks. The set of defined landmarks is quite large but only about 32 are the most commonly used as defined by Rocks [2].

The effective evaluation of radiographs depends on accurate definition and localization of landmarks, which provides the basis for all further analysis known as linear and angular reference lines as shown in fig.1 (a) and (b). The task of locating the landmarks on digitized X-ray images is a difficult task and requires more than 15 minutes for an experienced orthodontist. These difficulties comes from the fact that a slight shift in the orientation of the skull will generate a shift in the overlapping features and the shapes of landmarks would differ in two x-ray of the same patient taken at the same time.

Automatic location of landmarks has been subject to research for many years. Many researchers have tried to repeat the procedures followed by orthodontists by producing a trace of the skull and then tried to locate the land marks on the line crossing according to their geometric definitions [3][4].



(a) (b)

Figure 1. The most commonly used landmarks with (a) linear measurements and (b) angular measurements

These systems can only detect landmarks located on or near edges and its performance relies on the quality of the x-rays. Cardello and SidAhmed[5] used mathematical modeling to reduce the search are for the landmarks and then applied template matching techniques based on mathematical morphology to pin point the exact location of the landmarks. The algorithm was tested on 20 X-ray images and it located 76% of 20 landmarks with accuracy of less than ±2mm which is the accepted accuracy of a landmark location. El-Feghi *et al*. [1] [6] have used neural networks to find the locations of landmarks by extracting features from the skull X-ray. They were able to accurately locate 20 landmarks on more 150 images. Chakrabartty *et al* [7] applied support vector machines (SVM) to detect 16 landmarks with accuracy of more than 95%. Recently, Yue *et al*[8] have developed an algorithm based on the use of four-point subdivision curves to trace out all the craniofacial structures and locate 12 reference landmarks. They reported recognition rate of 71% with acceptable accuracy of ±2mm on 79 images.

Because of the large variability in the morphology of the human head, large variation of special coordinates of landmarks are observed and must be reduced. To reduce this variation adaptive localization based on the size, rotation and shifts of the skull is used.

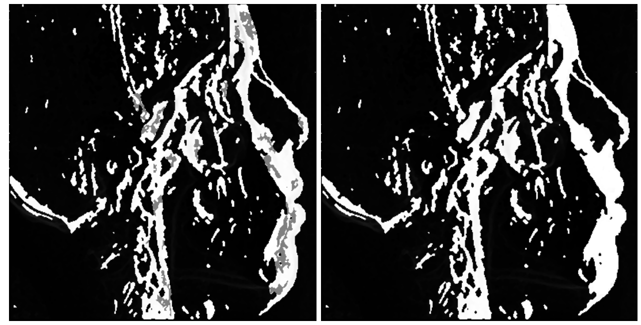
In this paper, we present a new approach to the localization of craniofacial landmarks based image registration of lateral skull profile using affine transformation. The localization algorithm can be divided into several stages as follows: 1. Preprocessing: image enhancement, edge detection, filtering and thresholding.
2. Features extractions. Extracting nine fiducial points in the outer x-ray profile. 3. Determining the transformation function by determining the correspondence between control points of the reference image and target image. 4.: Mapping the landmarks from the reference image to the target image based on the transformation function obtained in the previous stage. Since the control points(nine fiducial points) are known in the reference and target image and obtained as outlined the section II, they can be used to determine the transformation function. Once the transformation function is obtained, it is used to find the location of the craniofacial landmarks by using the transformation function to map a labeled reference image to the target image.

II. FEATURES EXTRACTION

The method developed here is based on first highlighting the features of the image representing the soft and bonny structures using image processing techniques. Contrast stretching by histogram equalization [9] is applied to enhance the appearance of the images. Next, Sobel operator is used to extract the most important edges of the skull then a 5×5 median filter is used to remove the noise from the resultant image. Images are then converted to binary by thresholding [10] to show the outer edge of the skull. Fig.2(a-d) shows the preprocessing steps outlined previously.

(a) **(b)**

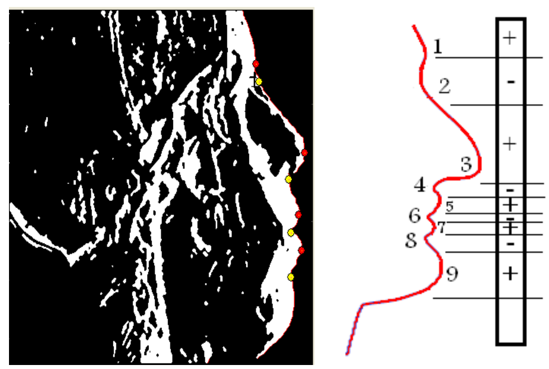
Figure 2 (a) Original Image (b) after applying edge detector



(c) (d)

(c) after applying 5x5 median filter (d) binary image

Face profile is achieved by exploiting knowledge of the anatomical structure of the face. Nine fiducial marks are expected for a typical face as in fig.3(a) and (b). The nine points include the forehead, bridge, nose, nose bottom, upper lip, mouth, lower lip, chin cleft, and chin tip. The signs of the curvature corresponding to concave and convex regions of the landmarks follow an alternating pattern. The localization of the fiducial marks is performed by beginning from the forehead toward the chin, the segment containing



(a) (b)

Figure 3: (a) typical laterl skull x-ray image with nine fiducial point identified.(b) nine fiducial landmarks are identified whose curvature sign follows the pattern +,-,+,-,+,-,+,-,+ following corresponding to transitions between convex and concave regions of the profile.

III. **IMAGE REGISTRATION**

Image registration is referred to as the process of aligning data into reference space. The main purpose of this alignment is to identify common features of interest in the data by using the atlas associated with the reference volume. In the case of studying landmarks localization, we are interested in finding a geometric transformation that maps the nine fiducial points on the reference image into the target. The problem to be addressed is as follows. Given the coordinates of N corresponding control points in two images of a scene

$\{(x_i, y_i),(X_i, Y_i)$i=1,…,$N\}$ (1)

determine a transformation function f(x,y) with components $f_x(x,y)$ and $f_y(x,y)$ and that satisfy

$Xi \approx f_x(x,y)$ (2)

$Yi \approx f_y(x,y) \quad i = 1,\dots,N$ (3)

Once f(x,y) is determined, given the coordinates of a point in *reference* image, the coordinates of the corresponding point in the *target* image can be determined.

Given a set of corresponding control points in *reference* and *target* images, many transformation functions can be found to accurately map the control points in the *target* image to the corresponding control points in the *reference* image. A proper transformation will accurately map the remaining points (landmarks) in the target image to the corresponding points in the reference image also.

A. LEAST SQUARE ESTIMATOR

To come up with a model suitable for transforming control points from target image to reference image, we will use Lease Square Error (LSE) to minimize the error in transformation.

Let points in the target image q

$$Q = \begin{bmatrix} q_0 \\ q_1 \\ \cdot\cdot \\ \cdot \\ q_n \end{bmatrix} \qquad q_i \;\; i = 0,\dots,n \tag{4}$$

n is the number of points. Points in the reference image are p.

$$P = \begin{bmatrix} p_0 \\ p_1 \\ \cdot \\ \cdot \\ p_n \end{bmatrix} \qquad p_i \; i = 0,\dots,n \tag{5}$$

Q=***P k***+ ***e***, k =[$k_0, k_0, \dots, k_n$] (6)

is an *nx1* unknown parameter vector and *e* is the error vector. Instead of finding exact solution to Equation(4), we will search for $k=\bar{k}$ which minimizes the sum of squared error defined by

$$\mathrm{E(k) = (Q - Ak)^T(Q - Ak)} \tag{7}$$

If $\mathrm{P\,P^T}$ is non singular, then $\bar{\mathrm{k}}$ can be solved uniquely.

$$\bar{\mathrm{k}} = \mathrm{(P\,P^T)^{-1}\,p^T\,Q} \tag{8}$$

To improve the model suitable for mapping points between image we can increase the model's degrees of freedom by introducing terms of higher order:

$$q = k_0 + k_1\,p + k_2 p^2 + k_3 p^3 + \dots + k_n p^n \tag{9}$$

The same identification procedure can be performed to find the LSE for $k = [k_0, k_1, \dots, k_n]^T$ which results in a least square polynomial that minimizes the squared error.

The squared error will decrease as the degree of the polynomial is increased. However, although it fits the mapping function better, polynomial with higher order does not always reflect the true characteristics of the system in question. An easy way to select the proper degree of the polynomial is to apply another input-output data set, called the validating or test set, that was not used in the construction of the LSE model. This data set can verify the generalization capabilities of the resulting method and provide an index for selecting the degree of the polynomial.

IV. EXPERIMENTAL RESULTS

Starting with 200 x-ray images, we have selected several images to be used as references. One reference image is selected for each sex, race and closer ages. Having selected the reference image, their outer control points are extracted based on the outlined procedures. The landmarks shown in Fig. 4 are labeled by the human expert. The next step is to obtain the control points on the target image and then the mapping polynomial is obtained using the nine fiducial points. The landmarks on the target image are then obtained by mapping the landmarks on the reference image to their expected position on the target image. The predicted positions are evaluated by the human expert. If the difference between the obtained location and the expected location is <= ±2mm, is considered correct localization otherwise it is considered wrong localization. Table 1 shows the results of locating 15 landmarks in all images of the test set.

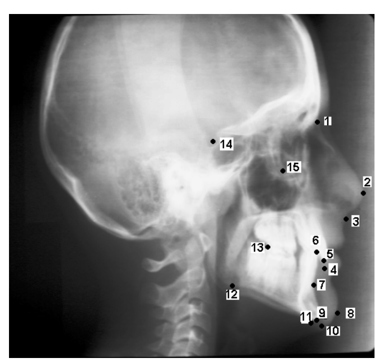


Figure.5 Locations of some of the landmarks on the lateral skull radiograph

Table 1. Recognition rates of 15 selected landmarks

No	Name	Rate
1	Nasion (N)	100%
2	Tip of the nose	100%
3	(Subnasal) SN	91%
4	Incisor superius.IS	85%
5	Anterior point for the occlusal plane APOcc	82%
6	Infradentale, Ii	92%
7	superamentale	89%
8	Soft tissue pogonion	91%
9	Gnathion	96%
10	The anterior landmark for determining the length of the mandible	88%
11	Menton	94%
12	Gonion	93%
13	Posterior Point of the occlusal plane	92%
14	Sell	88%
15	Orbitale	90%

V. Conclusions

In this paper, we have shown that most of the craniofacial landmarks can be located using least square error approximator. The approximation was successful due to the fact that there is enough correlation between the points located on the outer contour, the size of the skull, the age and the race of the patients and the location of the craniofacial landmarks. We have also demonstrated that non rigid image registration can be used to map the location of landmark between labeled images and input images. Results obtained using the outlined algorithm demonstrated that an average of 91% of the localization of 15 selected landmarks within a window of <= ±2mm pixels was successful.

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