ORIGINAL ARTICLE

Accuracy of computerized automatic identification of cephalometric landmarks

Jia-Kuang Liu, DDS,[a] Yen-Ting Chen, MSD,[b] and Kuo-Sheng Cheng, PhD[c]
Tainan, Taiwan, ROC

Computerized cephalometric analysis can include both landmark identification and determination of linear or angular measurements. Although its use is time saving compared with a manual method, the accuracy of automatic landmark identification remains unclear. The purpose of this study was to evaluate the accuracy of a computerized automatic landmark identification system that used an edge-based technique. The technique divides the scanned cephalogram into 8 rectangular subimage regions. After the resolution of these subimages is reduced, the edges are detected and the landmarks are located automatically. Thirteen landmarks were selected for assessment on a set of 10 test cephalograms. The results showed that the errors between manual and computerized identification for landmarks were not significantly different ($P > .05$) for 5 of 13 landmarks: sella, nasion, porion, orbitale, and gnathion. These results suggest that the accuracy of computerized automatic identification is acceptable for certain landmarks only. Further studies to improve the accuracy of computerized automated landmark identification are needed. (Am J Orthod Dentofacial Orthop 2000;118:535-40)

Cephalometric analysis is an important tool for orthodontic diagnosis and treatment planning. Manual cephalometric analysis is time-consuming, and computer-aided analysis can offer considerable time savings. Most computerized cephalometric analyses use manual identification of landmarks based either on digitizing them or locating them on the monitor.[1,2] The methods of landmark identification are the main source of error in computerized cephalometric analysis. In addition, interobserver or intraobserver differences can also affect results. Interobserver differences may be caused by variations in training and experience of the observers. Intraobserver differences may result from the quality of the headplate and blurring of the anatomic structures.[3,4] Thus, computer-aided landmarking should both save time and eliminate observer-related manual errors. Cohen and Linney[5] were the first to develop a method for automatic landmark identification. They acquired and displayed a radiographic image on a monitor. A cellular logic image processor was then used to process the image. After image enhancement and application of the landmarking algorithm, menton and sella were located. In 1986, Levy-Mendel et al[6] proposed a knowledge-based landmarking method. The digitized radiographic image was processed using a prefiltering operator and an edge detector to obtain the edges. The useful lines were then extracted with a knowledge-based line-tracking algorithm. The knowledge included the approximate location of lines, the starting and ending conditions of lines, and the number of segments in the lines. Afterward, the landmarks were located by simple geometric definitions. In 1989, Parthasarathy et al[7] used the pyramid method to reduce the resolution of the image before prefiltering, contrast enhancement, and edge detection. They proposed an algorithm to locate the landmarks, with the resulting errors similar to those of 2 experts. The algorithm was also implemented to locate landmarks on the soft tissue face; the errors of landmark identification were smaller than 1 mm.[8,9] Cardillo and Sid-Ahmed[10] stated that the edge-tracking technique required good quality radiographic images. If a radiographic image contained extra or fragmental lines, the critical lines defining the landmarks might not be tracked properly. They developed a target recognition algorithm based on gray scale mathematical morphology to extract craniofacial landmarks. Their system located 20 landmarks with an 85% recognition rate. Rudolph et al[11] used spatial spectroscopy based on a convolution of the image with a set of filters followed by a decision method using statistical pattern

This research was supported by grants NSC 80-0404-E-006-52, NSC 83-0412-B-006-076 & NSC 84-2331-B-006-009 from the National Science Council, Taiwan, ROC.
[a]Assistant Professor, Department of Dentistry, College of Medicine, National Cheng Kung University; Chair, Division of Orthodontics and Department of Dentistry, National Cheng Kung University Hospital.
[b]PhD Student, Institute of Biomedical Engineering, National Cheng Kung University.
[c]Professor and Chair, Institute of Biomedical Engineering, National Cheng Kung University.
Reprint requests to: Jia-Kuang Liu, Department of Dentistry, National Cheng Kung University Hospital, 138 Sheng-Li Road, Tainan 704, Taiwan, ROC; e-mail, jkliu@mail.ncku.edu.tw.
Submitted, December 1999; revised and accepted, April 2000.

0889-5406/2000/$12.00 + 0 **8/1/110168**
doi:10.1067/mod.2000.110168

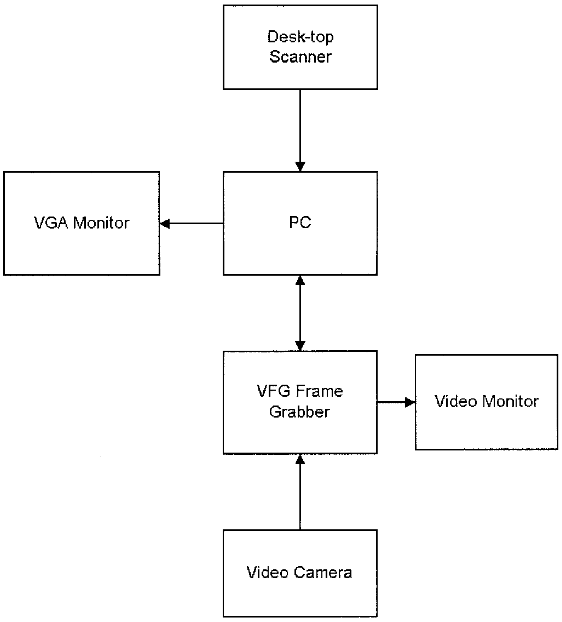

Fig 1. PC-based image processing system with desktop scanner.

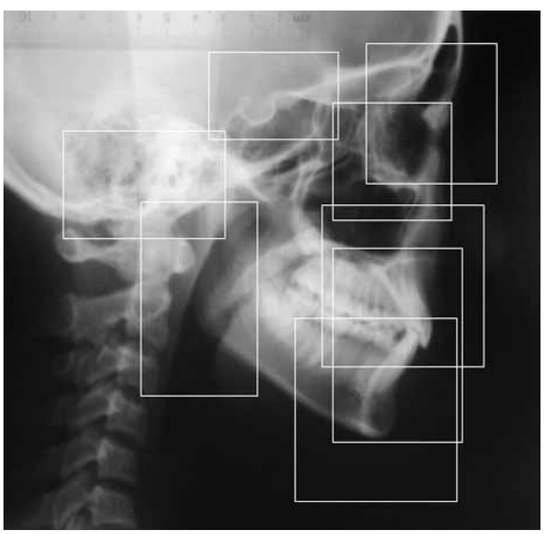

Fig 2. Cephalometric radiograph image divided into 8 rectangular subimage regions.

recognition techniques to automatically locate landmarks. They showed no statistical difference in mean landmark identification errors between manual and computerized methods for 15 landmarks. The purpose of this study was to evaluate the accuracy of a heuristic image processing approach for an automatic landmark identification system developed and used in National Cheng Kung University.

Fig 3. Curve of sella was located.

MATERIAL AND METHODS

Ten previously taken lateral cephalograms were selected at random from the orthodontic division at National Cheng Kung University Hospital. The PC-based image-processing system with a desktop scanner used for locating the landmarks of a cephalogram is shown in Fig 1. The radiographic cephalogram is first digitized by a desktop scanner and then preprocessed to define the machine ear rod as a reference point for later use. The image is then divided into 8 rectangular subimage regions (Fig 2) that contain all 13 landmarks (Table I). The resolution of these subimages is reduced, and the edges are detected with the edge detectors or the best orientation edge detector. The curves of the prestored models are adjusted elastically to match the tracing of the target edges (Fig 3). Finally, the positions of the landmarks are located automatically with a knowledge-based algorithm (Fig 4).

The accuracy of the landmarks located by this system was compared with that of manual landmarking by an orthodontist. Manual landmarking was recorded on 5 occasions for a cephalogram by the orthodontist, and the data were then transferred to the computer by a digitizer. The bisecting line from the image of the cephalostat through the center of the machine ear rod (C point) was defined as y-axis, and the line perpendicular to the y-axis through C point was defined as x-axis (Fig 5). The mean of 5 measurements of each landmark was defined as the baseline landmark. Mean errors were defined as the mean magnitude in distance between the baseline landmark and were selected landmarks for all 10 cephalograms. These measurements were registered according to this coordinate system. Differences in the

Fig 4. Example of computerized automatic identification of cephalometric landmarks.

Table I. Thirteen landmarks of a cephalogram

Landmarks	*Description*
Sella	Midpoint of the hypothysial fossa
Nasion	Most concave point of the nasofrontal suture
Porion	Uppermost point of the external ear meatus
Orbitale	Lowermost point of the orbit
A point	Deepest point of anterior maxilla
ANS	Tip of anterior nasal spine
B point	Deepest point of the anterior mandible
Pogonion	Most anterior point of the chin
Gnathion	Most anteroinferior point of the chin
Menton	Most inferior point of the chin
Gonion	Intersection of the lines tangent to the posterior and inferior border of mandible
Upper incisal edge	Tip of the crown of the most anterior maxillary central incisor
Lower incisal edge	Tip of the crown of the most anterior mandibular central incisor

mean errors of manual and automatic landmarkings were compared by Student *t* test.

RESULTS

The mean landmarking errors in x and y directions and the distribution of landmark registration for manual and automatic landmark identification are shown in Tables II and III. Comparison of the mean landmarking errors for automatic and manual identification is shown in Table IV. All the errors made by automatic identification were larger than those made by manual identification. In both manual and computer-aided methods, sella was the most accurately identified landmark, and orbitale was the least. The differences between errors made by automatic and manual identification of sella, nasion, porion, orbitale, and gnathion were not statistically significant, whereas those made for identifying A point, ANS, B point, pogonion, menton, gonion, upper incisal edge, and lower incisal edge were significant ($P < .05$).

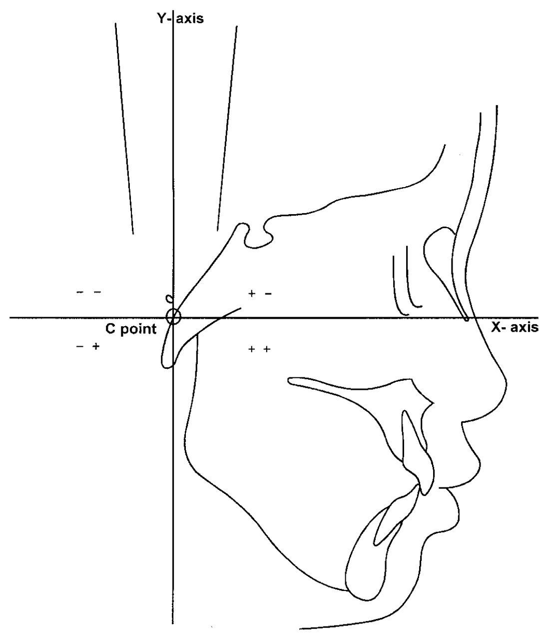

Fig 5. Coordinate system defined for landmark error analysis.

DISCUSSION

Two major techniques are used for automated landmarking: edge-based and region-based. The edge-based technique involves 3 steps: preprocessing, detecting edge, and locating landmark.[5-7] Preprocessing the image includes removal of noise, smoothing, and edge enhancement. Edge is detected by either line tracking or knowledge-based methods.[6,7] Then a knowledge-based algorithm is used to automatically locate the landmarks. Edge-based techniques carry the disadvantage that landmarks with unclear curves or edges may not be easy to identify. The present study uses an edge-based technique with 2 novel methods, subimage extraction and the elastic model, which was published previously,[12] to overcome this problem.

The region-based technique includes preprocessing, defining region, and locating landmark. Cardillo and Sid-Ahmed[10] developed a target recognition algorithm, and Rudolph et al[11] used spatial spectroscopy. The region-based technique has the following advan-

Table II. Mean errors for manual landmark identification

Landmarks	*Type of distribution*	*SDx (mm)*	*SDy (mm)*	*SD (mm)*
Sella	○	0.38 ± 0.21	0.47 ± 0.22	0.63 ± 0.23
Nasion	|	0.63 ± 0.33	1.38 ± 1.20	1.58 ± 1.17
Porion	|	1.14 ± 1.00	1.51 ± 1.86	2.07 ± 1.92
Orbitale	○	1.83 ± 0.79	1.70 ± 1.31	2.57 ± 1.39
A point	○	1.12 ± 0.90	1.07 ± 0.57	1.67 ± 0.85
ANS	—	1.74 ± 0.75	0.79 ± 0.35	1.93 ± 0.77
B point	|	0.65 ± 0.26	1.16 ± 0.40	1.34 ± 0.44
Pogonion	|	0.64 ± 0.24	1.49 ± 0.65	1.63 ± 0.66
Gnathion	○	0.99 ± 0.29	0.76 ± 0.35	1.27 ± 0.40
Menton	—	0.88 ± 0.37	0.46 ± 0.13	0.99 ± 0.38
Gonion	|	1.08 ± 0.27	1.65 ± 0.87	2.01 ± 0.81
Upper incisal edge	○	0.50 ± 0.14	0.44 ± 0.20	0.69 ± 0.17
Lower incisal edge	○	0.55 ± 0.33	0.63 ± 0.57	0.85 ± 0.63

SDx, Standard deviation for error in horizontal direction.
SDy, Standard deviation for error in vertical direction.
SD, Standard deviation for total error.
○, Circular pattern.
—, Primary along horizontal axis.
|, Primary along vertical axis.

Table III. Mean errors for automatic landmark identification

Landmarks	*Type of distribution*	*SDx (mm)*	*SDy (mm)*	*SD (mm)*
Sella	○	0.57 ± 0.42	0.65 ± 0.52	0.94 ± 0.54
Nasion	|	1.15 ± 0.70	1.78 ± 0.70	2.32 ± 1.14
Porion	○	1.65 ± 1.68	1.50 ± 1.62	2.43 ± 2.10
Orbitale	|	2.58 ± 2.67	4.30 ± 3.58	5.28 ± 4.10
A point	|	1.83 ± 1.51	3.53 ± 1.75	4.29 ± 1.56
ANS	—	2.64 ± 1.08	1.15 ± 0.47	2.90 ± 1.12
B point	|	1.61 ± 1.39	3.11 ± 1.39	3.69 ± 1.55
Pogonion	—	1.97 ± 1.22	1.22 ± 0.97	2.53 ± 1.12
Gnathion	○	1.18 ± 0.73	1.14 ± 0.77	1.74 ± 0.86
Menton	○	1.12 ± 0.77	1.19 ± 0.88	1.90 ± 0.57
Gonion	○	3.04 ± 2.86	2.92 ± 2.17	4.53 ± 3.13
Upper incisal edge	|	1.74 ± 1.67	1.31 ± 1.47	2.36 ± 2.01
Lower incisal edge	|	1.77 ± 1.06	1.03 ± 1.00	2.86 ± 1.24

SDx, Standard deviation for error in horizontal direction.
SDy, Standard deviation for error in vertical direction.
SD, Standard deviation for total error.
○, Circular pattern.
—, Primary along horizontal axis.
|, Primary along vertical axis.

tages: it uses rich structural information from the gray scale geometry of the image, it captures essential elements of object geometry such as “center” and “width,” and it measures across multiple scales.

The total mean manual error of landmark identification in the present study (1.48 mm) was slightly higher than in a previous study[3] (1.26 mm). In practice, a landmark location with an error below l mm is considered a precise measurement.[2] The accepted normal range of most cephalometric measurements in the radiographic image is roughly ±2 mm.[8] In the manual method of this study, S was the most precisely located landmark (error = 0.63 mm), and the locations of UIE and Me were also very precise (< l mm). Or was the least accurately located landmark (error = 2.57 mm), and the locations of Po and Go were not precise either (> 2 mm). Other landmark identifications were acceptable (l mm < errors < 2 mm). In the automatic method, S was the only precisely located landmark (0.94 mm). Gn and Me were acceptable, and the rest were not precise (> 2 mm). The distribution of landmark registration was divided into 3 types: circular pattern, primary along the horizontal

Table IV. Comparison of the mean errors for automatic and manual landmark identification

Landmarks	*Automatic error (mm)*	*Manual error (mm)*	*t test*
Sella	0.94 ± 0.54	0.63 ± 0.23	NS
Nasion	2.32 ± 1.14	1.58 ± 1.17	NS
Porion	2.43 ± 2.10	2.07 ± 1.92	NS
Orbitale	5.28 ± 4.10	2.57 ± 1.39	NS
A point	4.29 ± 1.56	1.67 ± 0.85	*
ANS	2.90 ± 1.12	1.93 ± 0.77	*
B point	3.69 ± 1.55	1.34 ± 0.44	*
Pogonion	2.53 ± 1.12	1.63 ± 0.66	*
Gnathion	1.74 ± 0.86	1.27 ± 0.40	NS
Menton	1.90 ± 0.57	0.99 ± 0.38	*
Gonion	4.53 ± 3.13	2.01 ± 0.81	*
Upper incisal edge	2.36 ± 2.01	0.69 ± 0.17	*
Lower incisal edge	2.29 ± 1.00	0.85 ± 0.63	*
Total mean error	2.86 ± 1.24	1.48 ± 0.59	*

NS, Not significant.
*$P < .05$

Table V. Comparison of the mean errors (mm) for automatic landmark identification in 2 studies

Landmarks	*Liu et al*	*Rudolph et al*
Sella	0.94 ± 0.54	5.06 ± 3.37
Nasion	2.32 ± 1.14	2.57 ± 2.18
Porion	2.43 ± 2.10	5.67 ± 4.93
Orbitale	5.28 ± 4.10	2.46 ± 3.77
A point	4.29 ± 1.56	2.33 ± 2.63
ANS	2.90 ± 1.12	2.64 ± 3.06
B point	3.69 ± 1.55	1.85 ± 2.09
Pogonion	2.53 ± 1.12	1.85 ± 2.26
Gnathion	1.74 ± 0.86	—
Menton	1.90 ± 0.57	3.09 ± 3.46
Gonion	4.53 ± 3.13	—
Upper incisal edge	2.36 ± 2.01	2.02 ± 1.99
Lower incisal edge	2.29 ± 1.00	2.46 ± 2.49
Upper incisal apex	—	2.17 ± 2.98
Lower incisal apex	—	2.67 ± 3.02
TMJ	—	5.07 ± 4.26
Mandibular notch	—	4.25 ± 3.93
Total mean error	2.86 ± 1.24	3.07 ± 3.09

axis, and primary along the vertical axis. Our study showed that the distribution of landmark registration by the manual method was in accordance with previous studies,[2,3,13] but that distribution by the automatic method was not.

The mean error of automatic landmarking in the present study was much higher than that of 2 previous studies, but slightly lower than another study.[5,7,11] Cohen and Linney's[5] result (1.55 mm) was close to that of manual landmarking, but they studied 2 easily identified landmarks–sella and menton. The magnitude of error in landmark identification depends on the position of the landmark. If the landmark is in a clear border of the craniofacial structure, as sella and menton are, the error will be smaller. However, if the landmark is in a blurred area of the craniofacial structures, as are porion and orbitale, the error will be larger.[3,14] The total mean automatic landmark error in the study of Parthasarathy et al[7] was 2.06 mm. The smaller error in their study can be attributed to the location of all landmarks in a clear border. In contrast, the total mean errors of landmark identification in Rudolph et al[11] and in the present study were similar (3.07 ± 3.09 mm; 2.86 ± 1.24 mm; Table V), and both studies identified more landmarks than Parthasarathy. The errors in the present study were larger than those of Rudolph for orbitale, A point, and B point, whereas errors for sella, porion, and menton were smaller. Rudolph et al claimed that using spatial spectroscopy methods to identify landmarks could be easier than using edge-based techniques. However, comparison of the errors of landmark identification in their study with those of ours does not support this claim.

More accurate methods of automated landmarking are needed to justify its use in orthodontics. The error of automatic identification must be less than or close to that of manual identification. Edge-based and region-based techniques each have unique advantages. A combination of these 2 methods may provide a better way to identify landmarks automatically.

CONCLUSION

In the present study, we found that only 5 of 13 landmarks identified by computer-aided landmarking were located with accuracy similar to that of manual landmarking. Further improvements in the accuracy of automated landmarking techniques that consider the complexity of the skull structure are needed.

REFERENCES

1. Baumrind S, Miller DM. Computer-aided head film analysis: the University of California San Francisco method. Am J Orthod 1980;78:41-65.
2. Richardson A. A comparison of traditional and computerized methods of cephalometric analysis. Eur J Orthod 1981;3:15-20.
3. Baumrind S, Frantz RC. The reliability of head film measurements. 1. Landmark identification. Am J Orthod 1971;60:111-27.
4. Savage AW, Showfety KJ, Yancey J. Repeated measures analysis of geometrically constructed and directly determined cephalometric points. Am J Orthod Dentofacial Orthop 1987;91:295-9.
5. Cohen AM, Linney AD. A preliminary study of computer recognition and identification of skeletal landmarks as a new method of cephalometric analysis. Br J Orthod 1984;11:143-54.
6. Levy-Mandel AD, Venetsanopoulos AN, Tsotsos JK. Knowledge-based landmarking of cephalograms. Comput Biomed Res 1986;19:282-309.
7. Parthasarathy S, Nugent ST, Gregson PG, Fay DF. Automatic landmarking of cephalograms. Comput Biomed Res 1989;22:248-69.

8. Tong W, Nugent ST, Gregson PH, Jensen GM, Fay DF. Landmarking of cephalograms using a microcomputer system. Comput Biomed Res 1990;23:358-79.
9. Mostafa YA, E1-Mangoury NH, Salah A, Rasmy EM. Automated cephalographic soft tissue analysis. 1990;24:539-43.
10. Cardillo J, Sid-Ahmed MA. An image processing system for locating craniofacial landmarks. IEEE Trans Med Imag 1994;13:275-89.
11. Rudolph DJ, Sinclair PM, Coggins JM. Automatic computerized radiographic identification of cephalometric landmarks. Am J Orthod Dentofacial Orthop 1998;113:173-9.
12. Chen YT, Cheng KS, Liu JK. Improving cephalogram analysis through feature subimage extraction. IEEE Engineering Med Biol 1999;18:25-31.
13. Stabrum AE, Danielsen K. Precision in cephalometric landmark identification. Eur J Orthod 1982;4:185-96.
14. Broch J. Slagsvold O, Rosler M. Error in landmark identification in lateral radiographic headplates. Eur J Orthod 1981;3:9-13.