European Journal of Orthodontics 18 (1996) 471–478

Assessment of an automated cephalometric analysis system

D. B. Forsyth* and D.N. Davis**
*Orthodontic Department, Leeds Dental Institute, University of Leeds, and **Department of Oral Health and Development, University Dental Hospital of Manchester, UK

SUMMARY A system is described which automatically identifies cephalometric landmarks on digital cephalometric radiographs. The accuracy of the automated system in identifying nineteen cephalometric landmarks is assessed. The accuracy obtained with the automated system is less than that of manual tracing. The automated system has particular difficulty in identifying landmarks which lie on poorly defined structures where there is a poor signal to noise ratio.

Introduction

The development of the computerized gamma camera and computed tomography in the early 1970s marked the first widespread medical application of digital imaging. Use of digital imaging now includes computed tomography, ultrasound, nuclear medicine, magnetic resonance, and digital subtraction angiography. More recently, digital imaging has been applied to conventional radiography including cephalometry.

A digital image is represented as a matrix of square pieces, or picture elements (pixels), that form a mosaic pattern from which the original image information can be reconstructed for visual display. Each pixel has a digital value that represents the intensity of the information recorded by the detector at that point. An analogue image, such as a radiographic film, has virtually an infinite number of elements with each element represented by a continuous grey scale. The quality of a digital image is strongly dependent on both the number of pixels and the number of grey levels which make up the image. Studies have been carried out comparing cephalometric digital images with their conventional counterparts with regard to image quality (Macrì and Wenzel, 1993).

Digital imaging applied to cephalometry may have several potential advantages including: (i) automated or semi-automated cephalometric analysis; (ii) reduction in radiation exposure to the patient; (iii) the ability to optimize image contrast and brightness; (iv) image enhancement; (v) the archiving and improved access to images; (vi) image transmission; (vii) superimposition of images; and (viii) as an aid to surgical planning of cases.

Automated or semi-automated cephalometric analysis

With the introduction of digital imaging, automated and semi-automated landmark identification have been investigated. If automated landmark identification were possible this would reduce the need for manual tracing of radiographs and remove operator subjectivity.

Medical applications where machine perception techniques have been investigated include the screening of blood samples, histological sections and in the assessment of radiographs. Automated systems where computer-aided diagnosis applied to chest radiographs and mammograms have been investigated. With regard to cephalometric analyses, several systems have shown varying degrees of success in identifying different landmarks on digital images. Landmarks on well defined edges such as menton and glabella can be located with some success, whereas landmarks such as posterior nasal spine, situated in 'busy' areas of the image where there is a low signal to noise ratio, prove more difficult to locate.

Lévy-Mandel *et al.* (1986) developed a process for automated landmark identification. The process is divided into three basic stages:

(i) edge enhancement, a median-smoothing filter was used followed by a Mero-Vassy edge operator (to provide edge enhancement); (ii) line extraction, a knowledge-based line-tracking algorithm was used. This compares extracted lines from the image to a model of expected lines; and (iii) landmark identification, from detected lines.

This system had a poor success rate unless images were of good quality. On two good quality images, 23 out of 36 landmarks were identified.

In a more extensive study by Parthasarathy *et al.* (1989) a different approach to Lévy-Mandel *et al.* (1986) was used. A resolution pyramid was used to extract relevant lines in a given region using a feature recognition technique. This system located nine landmarks on five radiographs. In all, 83 per cent of the landmarks identified by the automated system were within a three pixel radius (approximately 1 mm) of the corresponding landmark identified by two orthodontists. The system took approximately 10 minutes to perform the analysis.

Tong *et al.* (1990) suggested that the method used by Lévy-Mandel *et al.* (1986) was particularly dependent on the quality of the original image. Tong *et al.* (1990) used a process of edge enhancement and thresholding followed by edge detection techniques to identify 27 commonly used cephalometric landmarks. With this system 17 of the 27 landmarks were identified successfully, although the criteria for success was not indicated.

Previous attempts at automating cephalometric analyses failed to produce consistently good results with radiographic images of varying quality for a number of reasons. Firstly, the image operations in these systems, particularly segmentation (the extraction of image features) were not able to adapt to poor quality images. In addition, the models used as an aid to segmentation made little use of expected measurements of length, orientation and shape found on cephalometric radiographic images. Where such measurements were recorded no attempt was made to base them on a representative sample of training images. A previous system described by Yan *et al.* (1986) permitted the cephalometric analysis to continue even if a particular feature was not located. However, the system was unable to modify its interpretation of the image in the light of the features located.

The system used in this study is detailed elsewhere (Davis and Taylor, 1989, 1991) but the following list summarizes the more important design aspects of the cephalometric analysis system used.

1. Cephalometric point and image feature selection.
2. Modelling the appearance and spatial organisation of cephalometric image features.
3. Spatial organisation models are used to predict image regions within which one would expect to find specific features.
4. The use of feature appearance models in finding image features (model-based segmentation) with adaptable image feature extraction methods.
5. The hierarchical organisation of cephalometric tasks.
6. Adaptive task completion behaviour, allowing difficult features to be found at a later stage.
7. Use of spatial organisation models in choosing between alternative candidates for an image feature.
8. Management of the current cephalometric task solution.
9. Display of results.

The system is similar to that used by Lévy-Mandel *et al.* (1986) in that it uses a knowledge-based approach, a blackboard system. The blackboard system allows multiple knowledge sources to communicate via a global data area. The cephalometric analysis consists of a number of activities which the blackboard architecture can co-ordinate through a central memory area. Figure 1 shows a schematic representation of the adopted architecture, with the knowledge sources responsible for the important activities highlighted.

The system uses a process where differences in grey level values of adjacent pixels can be identified to enable edges and features to be located. Landmarks can then be identified on the detected edges. Landmarks on well defined edges are initially located and from their position target areas can be constructed to help in the location of landmarks which lie on poorly defined structures where there is a low signal to noise ratio.

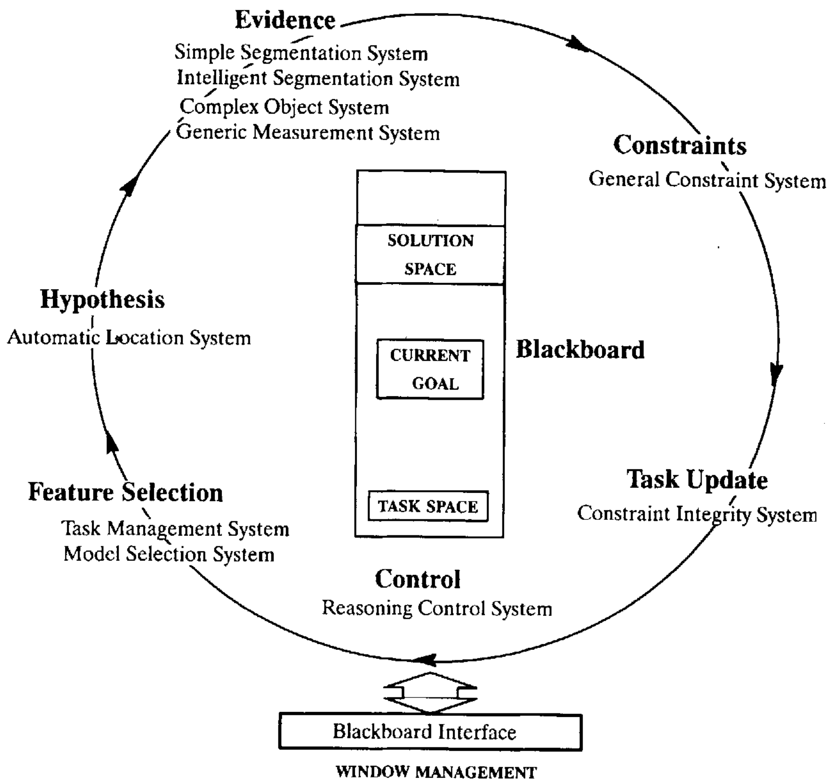

Figure 1 Blackboard architecture.

An example of an image interpreted by the automated system is shown in Fig. 2. The automated system appears to have made a reasonable estimate of identifying the landmarks menton, gonion, sella and glabella, whereas there are obvious errors in the identification of other landmarks such as anterior nasal spine and the upper incisor apex.

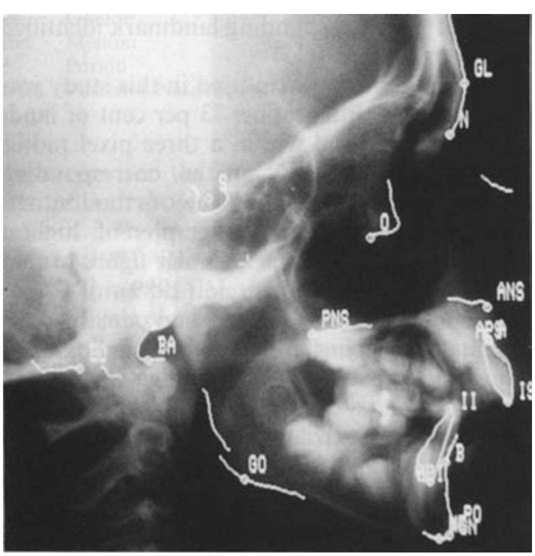

Figure 2 Example of image interpreted by the automatic system.

The aim of this study was to develop a system to automatically identify cephalometric landmarks on digital images of cephalometric radiographs and to assess the accuracy of the automated system.

Materials and methods

Sample

Ten cephalometric radiographs taken at the radiology department, Manchester Dental Hospital, UK, were used in this study. The radiographs were randomly selected disregarding the quality of the radiograph and the malocclusion present.

Exclusion criteria were: (i) obvious malposition of the head in the cephalostat; (ii) incisors unerupted or missing; and (iii) unerupted teeth overlying the apices of the incisors.

Digital images

In this study a Machine Vision Target System (MVT3020) (Advanced Vision Systems, Manchester, UK) was used to produce digital images of the cephalometric radiographs. It comprizes a 68020 VMEbus high-level language processor interfaced to an intelligent frame store. The cephalometric radiographs were captured using Pulnix TM-760 video camera (Pulnix Europe Limited, Basingstoke, Hampshire, UK) and displayed on a high resolution colour monitor. The images of the cephalometric radiographs were captured with the maxillary plane parallel to the horizontal plane of the display monitor.

The digital images displayed consist of a 512×512 pixel matrix, which gives a pixel size of approximately 0.3 mm with a resolution of 1 lp/mm (line pair per millimetre), with 64 grey levels.

Methods

Five experienced orthodontists manually identified landmarks on the digital images from which a mean clinicians' estimate was constructed for each landmark. The mean clinicians' estimate was then used as a baseline to compare with the automated system.

To obtain the mean clinicians' estimate the cephalometric analysis was carried out by the five orthodontists on two separate occasions for each of the 10 images. Therefore for each image, 10 estimations of each landmark were obtained from which the average clinicians' landmark could be constructed. A cephalometric analysis involving 19 cephalometric landmarks was undertaken on each of the 10 digital images (Fig. 3), the landmarks were digitized in a predetermined sequence. An agreement on the definition of the landmarks was established between the orthodontists prior to carrying out the cephalometric analysis. Landmarks were identified using a mouse-driven graphics cursor on the displayed digital image. Identified landmarks could be edited and their position changed until the operator was satisfied.

The automatic analysis was undertaken once on each of the 10 images identifying the same 19 landmarks. The computer was then able to compare the automatic system's estimate of a landmark with the mean clinicians' estimate.

Results

The orthodontists' and automatic system's estimates for the landmark Sella for two images are shown in Fig. 4. The 10 clinicians' estimations, with the constructed average clinicians' estimation (the origin) and automatic estimation are represented.

The accuracy of the automatic system is shown by the distance the automatic system's estimate is from the average clinicians' estimate. For each of the 10 images this distance was measured and a mean value was then calculated for each landmark. Figure 5 shows the mean distance the automatic estimation is from the mean clinicians' estimation for the ten images in the x axis, y axis and as a distance. Distances are measured in pixels, each pixel representing approximately 0.3 mm.

Discussion

A direct comparison with previous automated systems is not possible as the accuracy of automated systems is dependent on the quality of the radiographs being analysed. The system described by Parthasarathy *et al.* (1989) located nine landmarks on five radiographs. Of the five cephalometric landmarks one was considered to be of poor quality. In all, 83 per cent of the landmarks identified by the automated system were within a three pixel radius (approximately 1 mm) of the corresponding landmark identified by two orthodontists.

The automated system used in this study was applied to 10 radiographs; 73 per cent of landmarks were located within a three pixel radius (approximately 1 mm) of the corresponding landmark identified by the orthodontists. However, if the five radiographs of highest quality are selected, then a similar figure to that found by Parthasarathy *et al.* (1989), of 84 per cent is obtained. The current system has the advantage in being able to assess radiographs showing a greater range of image quality. In addition, the system can assess radiographs which show a variety of malocclusions, for example a radiograph of a patient with a severe Class III skeletal pattern. The current system also attempts to identify 19 landmarks as opposed to the nine landmarks identified by the system described by Parthasarathy *et al.* (1989).

For the automated system used in this study,

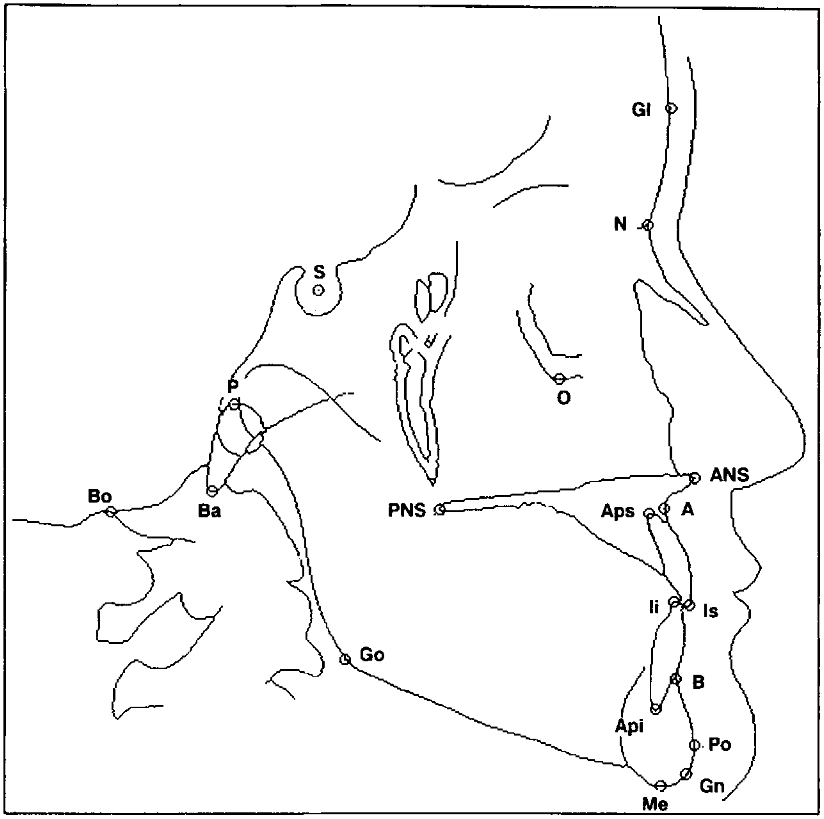

Figure 3 The 19 cephalometric landmarks used in the study.

A:	Point A	**ANS:**	Anterior Nasal Spine	**Api:**	Apicale Inferius
Aps:	Apicale Superius	**B:**	Point B	**Ba:**	Basion
Bo:	Bolton Point	**Gl:**	Glabella	**Gn:**	Gnathion
Go:	Gonion	**Ii:**	Incisor Inferius	**Is:**	Incisor Superius
Me:	Menton	**N:**	Nasion	**O:**	Orbitale
P:	Porion	**S:**	Sella Fossa	**Po:**	Pogonion
PNS:	Posterior Nasal Spine				

the errors for the majority of landmarks are greater than those expected with manual tracing as shown in previous studies (Baumrind and Frantz, 1971; Broch *et al.*, 1981). This may be due to three possible factors: (i) errors associated with the automatic system; (ii) the loss in image quality inherent in the digital image in comparison with the original radiograph (Macrì and Wenzel, 1993); and (iii) the radiographs selected in this study reflected a range of radiographic quality.

There are a number of possible improvements that could be made to the system. The system is unable to identify a landmark where a defining structure cannot be located. The feature appearance model could be changed in the light of more recent work on deformable templates (Cootes *et al.*, 1992), thus providing a model that would encompass and adapt to the features used in defining cephalometric landmarks. The segmentation system could also be improved using morphological operators to improve the definition of features (Kong and Rosenfeld, 1989). Alternatively the use of dynamic contour finding methods which adapt extracted edges to the model of the sought feature, may improve the identification of features on the radiograph (Kass *et al.*, 1987).

The quality of the digital images would be improved if images of greater spatial and grey level resolution were employed. However, this would lead to increased problems of data stor-

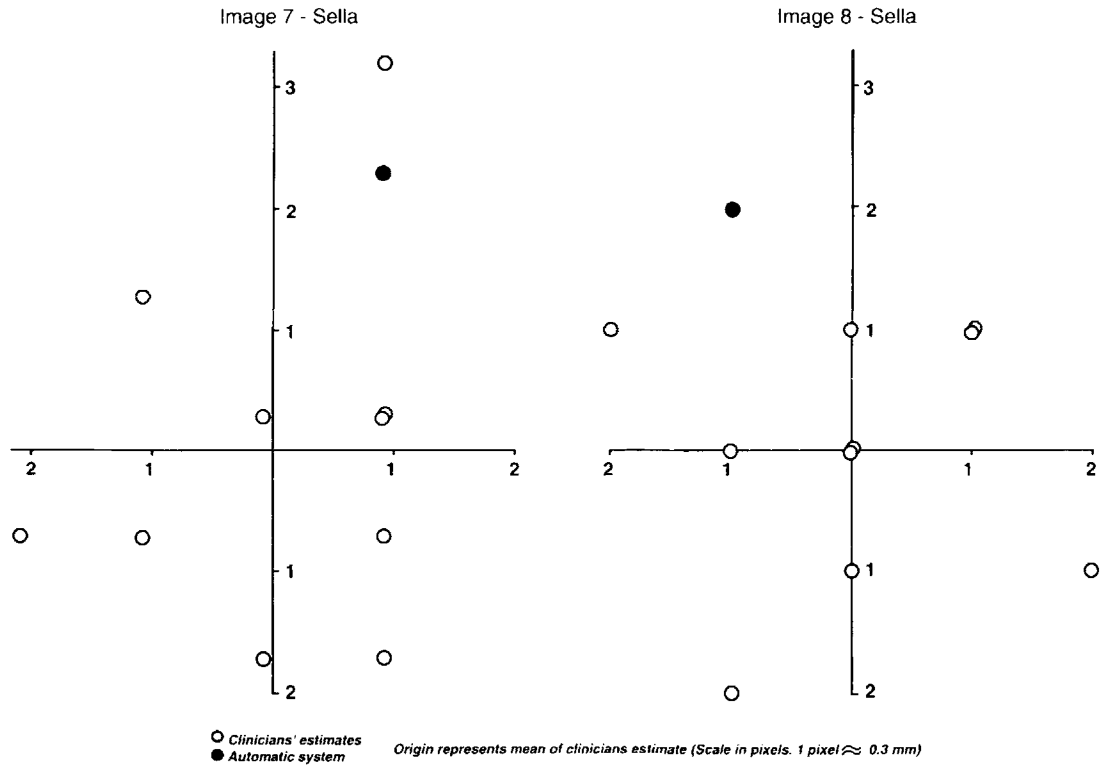

Figure 4 Clinicians' and automatic system's estimate for the landmark Sella for two images.

age and image manipulation. The accuracy of landmark identification by both manual and automated methods is limited by the size of the pixels. The digital image used in this study had a pixel size of 0.3 mm. Identification of a landmark can therefore only be located to the nearest 0.3 mm and this should be considered when interpreting the results.

Some landmarks are more accurately located than others. Large inaccuracies are associated with the computer system's placement of several landmarks, in particular orbitale, posterior nasal spine and anterior nasal spine. The mean error for the landmarks ANS, Api, Aps, Ba, Bo, O and PNS is >1 mm (3.33 pixels). These landmarks are located on poorly defined structures which have a low signal to noise ratio. Experienced clinicians may be able to infer the position of landmarks from their background knowledge of cephalometry, even if the landmark is poorly defined, whereas the automatic system is unable to compete in this capacity.

Landmarks that are located on structures that are clearly defined, where there is a high signal to noise ratio, are more accurately located. The mean error for the landmarks A, B, Gl, Gn, Go, Li, Ls, Me, N, P, Po and S is <1 mm (3.33 pixels). Only the landmarks A, Gl, Ls, Me, P and Po were identified with a mean error of <0.5 mm (1.67 pixels). Errors less than 0.5 mm are generally considered to be acceptable for manual identification of cephalometric landmarks.

The pattern of errors is similar to that found with manual tracing. Landmarks lying on horizontal edges or planes, such as the point PNS, are more accurately located in the vertical dimension as opposed to the horizontal dimension. Similarly, landmarks lying on vertical edges are more accurately located in the horizontal dimension.

The error associated with the automatic system will vary in magnitude and direction for individual landmarks between radiographs. However, if the automated system analyses the same radiograph under the same conditions then landmark identification is reproducible to the same pixel for each landmark.

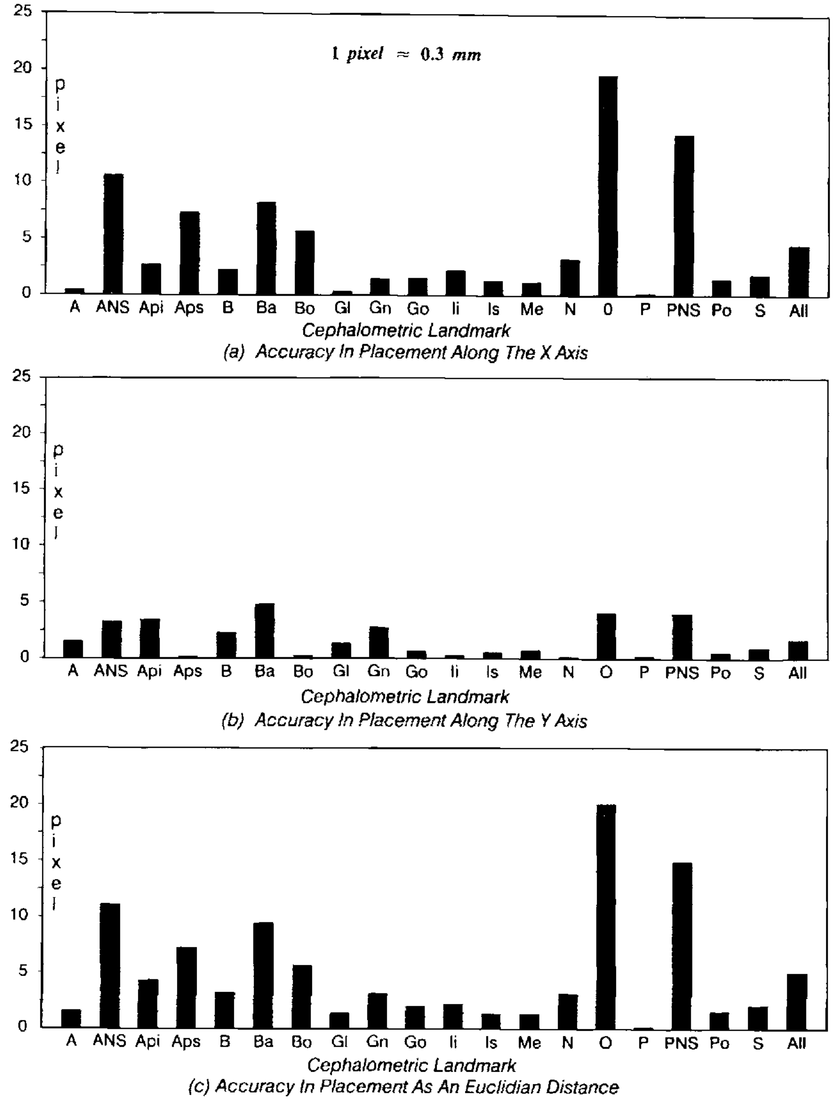

Figure 5. Accuracy of landmark location for the automatic system. The reference for each point in each image is given by the mean clinician point (average of 10 trials). Accuracy is given as the absolute mean of the differences, in x, y and distance.

Conclusions

This study describes a system that has been developed to automatically identify cephalometric landmarks on digital images. The accuracy obtained with the automatic system is comparable to previous automated systems but is not as accurate as manual identification of landmarks. Landmarks located on structures with a high signal to noise ratio, such as Menton and Glabella, can be more accurately located than those with a poor signal-to-noise ratio, such as Orbitale. Automated systems are at present unable to compete with manual identification of radiographs in terms of accuracy of landmark identification.

Address for correspondence

D.B. Forsyth
Orthodontic Department
Leeds Dental Institute
University of Leeds
Clarendon Way
Leeds LS2 9LU, UK

References

Baumrind S, Frantz R C 1971 The reliability of head film measurements and mark identification. American Journal of Orthodontics 60: 111–127

Broch J, Slagsvold O, Røsler M 1981 Error in landmark identification in lateral radiographic headplates. European Journal of Orthodontics 3: 9–11

Cootes T F, Cooper D H, Taylor C J, Graham J 1992 A trainable method of parametric shape description. Proceedings of the British Machine Vision Conference, pp. 54–61

Davis D N, Taylor C J 1989 An intelligent segmentation system for lateral skull X-ray images. AVC89, Proceedings of the Fifth Alvey Vision Conference, University of Reading, pp. 251–255

Davis D N, Taylor C J 1991 A blackboard architecture for automating cephalometric analysis. Medical Informatics 16: No. 2

Kass M, Witkin A, Terzopoulos D 1987 Snakes: active contour models. International Journal of Computer Vision 1: 133–144

Kong T Y, Rosenfeld A 1989 Digital topology: introduction and survey. Computer Vision Graphics and Image Processing 48: 357–393

Lévy-Mandel A D, Venetsanopoulos A N, Tsotsos J K 1986 Knowledge-based landmarking of cephalograms. Computers and Biomedical Research 19: 282–309

Macri V, Wenzel A 1993 Reliability of landmark recording on film and digital lateral cephalograms. European Journal of Orthodontics 15: 137–148

Parthasarathy S, Nugent S T, Gregson P G, Fay D F 1989 Automatic landmarking of cephalograms. Computers and Biomedical Research 22: 248–269

Tong W, Nugent S T, Gregson P H, Jensen G M, Fay D F 1990 Landmarking of cephalograms using a microcomputer system. Computers and Biomedical Research 23: 358–379

Yan C K, Venetsanopoulos A N, Filleray E D 1986 An expert system for landmarking of cephalograms. Proceedings of the 6th International Workshop on Expert Systems and Applications, pp. 337–356