ANALYSIS OF FACIAL PROFILES

JOÃO CARLOS CAMPOS

Department of Medical Physics and Bioengineering
University College London
London, England.

Abstract. This work presents some preliminary results of the project 'Analysis of Facial Profiles'. The aim is to establish a method of segmentation, description and classification of human facial profiles. Special emphasis is given to the analysis of changes in shape and the use of curvature variation along the profile. Mathematical techniques for quantitatively describing the changes produced by surgery have been developed, including methods of automatic profile segmentation and curvature analysis using scale space techniques. A medical graphics workstation is used for data analysis, which generates a three-dimensional model of the facial surface from data of CT, MRI scanners or from a custom built laser scanner, allowing the definition and extraction of a number of arbitrary sections (sets of x-y coordinate points). Mid-line facial profiles representing the pre and post-treatment states of a patient following surgery to the middle third of the face is used to illustrate some of the methods.

I - Introduction

This work was motivated by a practical problem faced during the project *'System for the Simulation and Planning of Facial Reconstructive Surgery Using Computer Graphics'* (supported by the UK Department of Health) in its final stage, during which an evaluation was carried out. The aim was to assess, from a qualitative and quantitative point of view, the predicted surgery performed using a computer graphics system. One of the criteria of this evaluation was based on the extraction of a set of profiles and on their comparison using statistical methods. Therefore a suitable metric to describe the changes which have occurred should be derived.

The study and the analysis of facial form can be, in a broader sense, related to the mathematical description of shape. Although this problem can be expressed in general terms and a general methodology can be developed, the identification of which information is relevant to a particular problem and in what way it should be presented are very important issues in the choice of a method of shape description.

Methods that provide a prediction in terms of facial appearance and soft tissue movement have become increasingly important in orthodontic and surgical treatments over the past decade. Here the use of computer based systems is obvious and disciplines like pattern recognition, computer vision, graphics and image processing are directly involved in providing the necessary methodologies and approaches that will help deal with this particular application.

The literature on shape analysis basically covers two areas of study: the statistical theory of shape and the techniques used to code shape. The amount of work produced is considerable (papers, essays, books, etc) with a great diversity of approaches, and will not be explored here.

Mathematical techniques to describe the facial shape and the changes occurring in the face may be applied to the analysis of (a) surfaces, by using three-dimensional(3D) data, or (b) profiles, by using two-dimensional(2D) data. However, a relationship between the two may be established in cases where sets of 2D data are a representation of a 3D object.

Although these techniques have been widely explored in the past few years they are both open research fields. The work described here is concentrated in the context where shape is defined within a two-dimensional field, i.e. shape of plane objects as defined by their contours or 'silhouettes'. Using this approach, several cephalometric procedures have been defined for the mid-sagittal facial profile and have proved quite useful. However, they are restricted to a particular profile and the qualitative judgements are always made based primarily on clinical experience. Therefore there is a need to develop a more objective approach to this analysis.

The aim of this work is to study human facial profiles. This involves establishing a method of segmentation, description and classification of profiles, not being restricted to whether we are analysing a single one or a set. The particular problems of quantifying changes in facial morphology are investigated.

II - Method of Analysis

The identification and location of points or landmarks is a very important issue in profile analysis and they play an important role in segmenting the profile as a pre-cursor for analysis. Here, the emphasis given is not so much in relative movements of landmarks as in the changes in shape of the segments between the landmarks.

The approach adopted on this work combines the following aspects: (1) the well recognized importance of curvature variation along the contour; (2) the view of curvature as a result of processes acting on the shape; (3) use of criteria that involve metric information extracted from curvature analysis; (4) use of contour segments bounded by perceptually relevant points (e.g. inflection and extremal points).

II.1 - Profile Segmentation

Through segmentation a profile may be objectively divided into a number of regions considered suitable for analysis, which are seen to correspond to parts of the face of interest to the clinician (e.g. nose, chin, etc).

The technique which was found to yield the best results for surface profiles is based on Scale Space techniques, reported in the pattern recognition literature [Mokhtarian-Mackworth (1986)]. These make use of filtering the signal across a continuum of scales by applying Gaussian filters and then tracking the extremal points and their derivatives as they move with scale changes. A mathematical expression that gives the curvature values of the points along the profile is used to compute the points of zero curvature value (called zero crossing or inflection points). The result is the Curvature Scale Space Image(CSSI) of the profile, a description of the zero crossing contours showing the appearance and motion of inflection points in the smoothed profile. Each zero-contour may be reduced to an (x,scale) pair, specifying its fine-scale location on the x-axis, and the coarsest scale at which the contour appears. Finally, the CSSI is reduced to a simple interval tree representing a qualitative description of the profile simultaneously at all scales. This description is then used to automatically identify and localize features in the facial profile.

This segmentation process is independent of the spatial orientation of the profile and free from subjective judgement. Unlike the analysis of landmark movements, the method does not require registering of profiles to be compared.

II.2 - Difference Measure

Quantifying facial profile changes due to growth, orthodontic treatment or surgery, is not an easy task. Although some statistical methods for comparing differences in shape and landmark movement are available, they are not so meaningful or easy to use from a clinician's point of view. Situations of a segment being bent (either to produce a concave or convex curve), compressed or extended should be meaningfully expressed by the difference metric to be derived.

The following techniques are used to establish a difference metric:

1. bending energy: is, by definition, the physical energy required to bend a straight rod to the shape represented by the given discrete contour. It borrows its concept and mathematical formulations from the elasticity theory;

2. spatial differences: when two profiles are registered, i.e. superimposing a region which has not been altered (e.g. forehead), the differences can clearly be seen. These may be presented as shaded areas so as to assist visual appreciation and assessment, or as a distance between corresponding points for the two profiles. The statistical distribution of distances may then be computed and histograms of distance plotted;

3. curvature value: of a planar curve at a point **P** on the curve is defined as the instantaneous rate of change of the slope of the tangent at point **P** with respect to arc length **S**, and is equal to equal to the inverse of the radius **R** of the circle of curvature (osculating circle) at point **P**. In order to compute the curvature values, the curve must be expressed in terms of two functions x(t) and y(t), where t is a linear function of the path length ranging over the closed interval [0,1]. The curvature value provides useful local shape information by which the segment can be described in terms of its concavity;

III - Material

A medical graphics workstation is used for data analysis [Tan et al. (1991)]. It has been developed consisting of PC hosted Transputer boards, and a set of computer graphics programs and application software tools.The computer system processes data from three sources: (1) a set of contiguous transaxial scans from CT or MRI scanners, (2) facial surface scans from the custom built laser scanner [Moss et al. (1989)], and (3) data traced from lateral radiographs. A three-dimensional model of the facial surface is generated from data from sources (1) or (2), allowing the definition and extraction of a number of arbitrary sections (sets of x-y coordinate points).

The data used in the analysis presented here consisted of mid-line facial profiles representing the pre and post-treatment states of a patient following surgery to the middle third of the face. The profiles were automatically segmented on a series of eight convex and concave curves, defined by nine points(or landmarks).

IV - Experimental Results

Figure 1 shows a pair of mid-line profiles extracted from a three-dimensional surface model of a face.

Figure 2 shows a sequence of outlines obtained by Gaussian convolution, using the profile from figure 1. The scale parameter increases by a factor of 0.5, ranging from a fine scale (equal 1 on the left) to a coarse scale (equal 10 on the right).

Figure 3 shows: the segmented profile, its curvature scale space image and interval tree descriptions, and the location of the defined zero crossing points(landmarks), which segment the profile into eight regions corresponding to: soft tissue nasion, nose, nasio-labial fold, upper lip, mouth, lower lip, labio- mental fold, and chin.

On figure 4, the curvature value for each point along the profile is plotted against the path length. The bending energy value may be used to express whether the segment has been elongated or compressed. The slope value may be used to identify the extremal points of a segment, e.g. the tip of the nose when the segment represents the nose. On figure 5, the curvature values quantitatively describe changes occurred.

V - Discussion

The idea of segmenting the profile using scale space techniques proved to be efficient as it avoids the problems of identification of landmarks by using mathematically constructed points. The reproducibility of this method was tested by repeat recording and measurement of the mid-line profile on several separate occasions. Although the contours in the scale space image may vary in shape the segments can always be identified.

The spatial difference metric between facial profiles was used in an attempt to provide the clinician with as good a view of the situation as possible. It has however been found to be quite sensitive to the accuracy of registration of the profiles. The advantage is that the statistics may be readily understood in terms of their relationship to the visual comparison and that emphasis is not placed on individual landmarks. However, such method alone only indicate one aspect of similarity or difference of two profiles. A suitable metric of difference should be also sensitive to shape, rather than simply to spatial difference.

The method of analysis using curvature values produces a pattern of concavity and convexity corresponding to the clinical perception of the profile, and gives a valuable shape description as one is able to quantify whether the segment has altered its curvature.

Further studies are now necessary to explore the usage of the methods described. Special attention should be given to the classification of the profile segments and to the possible correlation between the various methods. It should be possible to present some parameters that would classify the different facial features. For example, within the segment that represent the nose one might be able to characterize two or three types by considering the length of the spine, or the curvature of the tip of the nose, or even its alar base. Also some measure of the error on this classification should be provided, for a better evaluation of the techniques involved .

VI - References

F. Mokhtarian and A. Mackworth, Scale-Based Description and Recognition of Planar Curves and Two Dimensional Shapes, *IEEE-PAMI* **8** (1986) 34–43.

A.C. Tan, R. Richards and A.D. Linney, The MGI Workstation: An Interactive System for 3D Medical Graphics Applications, *CAR'91*, Springer-Verlag, Berlin, (1991) 705–710.

J.P. Moss, A.D. Linney, S.R.Grindrod and C.A. Mosse, A Laser Scanning System for the Measurement of Facial Surface Morphology, *Optics and Lasers in Engineering* **10** (1989) 179–190.

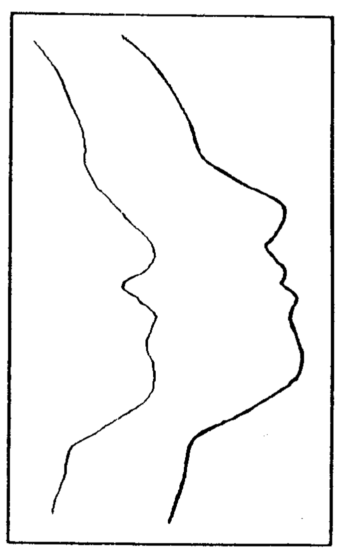

Figure 1 - Mid-line profiles: pre-surgery(left) and post- surgery(right).

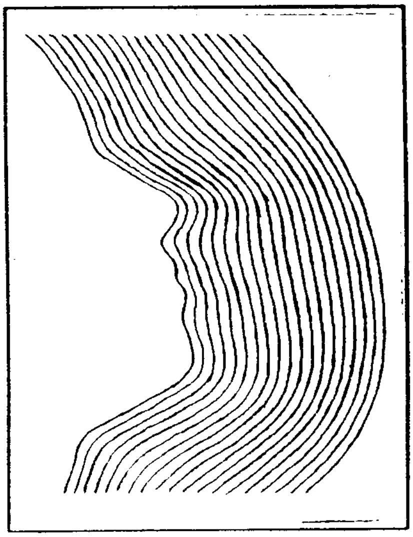

Figure 2 - Sequence of gaussian convoluted profiles. The scale parameter is increasing from left to right.

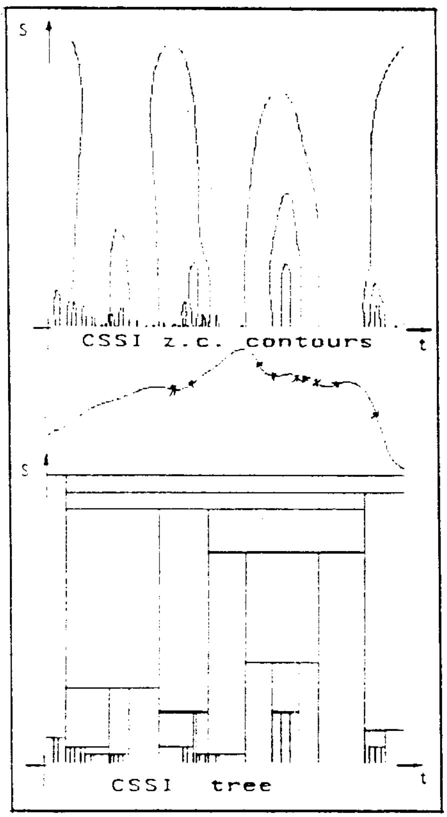

Figure 3 - The Curvature Scale Space Image (top) showing the zero crossing contours; followed by the segmented profile(centre) and by the interval tree description(bottom).The y-axis represent the scale (S) and the x-axis is the path length (t).

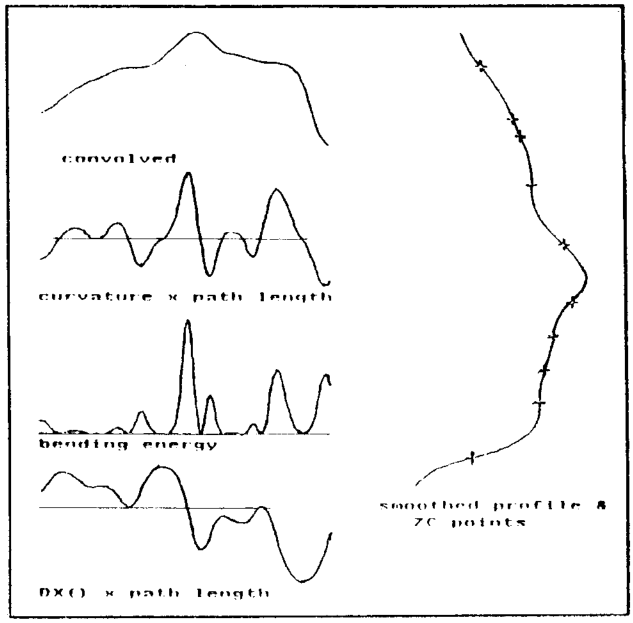

Figure 4 - On the left, the curvature, bending energy and slope values for each point along the profile are plotted against the path length where the horizontal line is to indicate zero. The profile and the inflection points are also shown(right side). The first inflection point at the top of the profile correspond to the first zero crossing(ZC) point on the left of the curvature plotting.

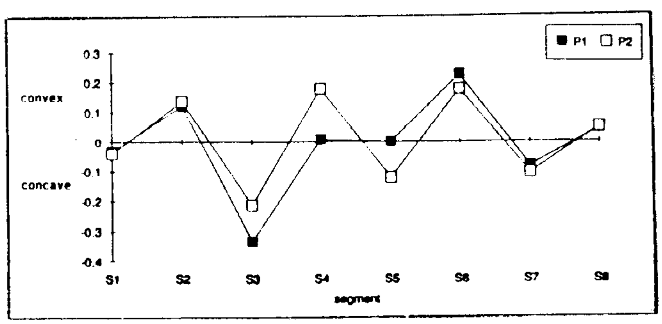

Figure 5 - Curvature plotting for the segmented profiles. Pre and post-treatment are given by P1 and P2 respectively.

were automatically segmented on a series of eight convex and concave curves, defined by nine points(or landmarks).

IV - Experimental Results

Figure 1 shows a pair of mid-line profiles extracted from a three-dimensional surface model of a face.

Figure 2 shows a sequence of outlines obtained by Gaussian convolution, using the profile from figure 1. The scale parameter increases by a factor of 0.5, ranging from a fine scale (equal 1 on the left) to a coarse scale (equal 10 on the right).

Figure 3 shows: the segmented profile, its curvature scale space image and interval tree descriptions, and the location of the defined zero crossing points(landmarks), which segment the profile into eight regions corresponding to: soft tissue nasion, nose, nasio-labial fold, upper lip, mouth, lower lip, labio- mental fold, and chin.

On figure 4, the curvature value for each point along the profile is plotted against the path length. The bending energy value may be used to express whether the segment has been elongated or compressed. The slope value may be used to identify the extremal points of a segment, e.g. the tip of the nose when the segment represents the nose. On figure 5, the curvature values quantitatively describe changes occurred.

V - Discussion

The idea of segmenting the profile using scale space techniques proved to be efficient as it avoids the problems of identification of landmarks by using mathematically constructed points. The reproducibility of this method was tested by repeat recording and measurement of the mid-line profile on several separate occasions. Although the contours in the scale space image may vary in shape the segments can always be identified.

The spatial difference metric between facial profiles was used in an attempt to provide the clinician with as good a view of the situation as possible. It has however been found to be quite sensitive to the accuracy of registration of the profiles. The advantage is that the statistics may be readily understood in terms of their relationship to the visual comparison and that emphasis is not placed on individual landmarks. However, such method alone only indicate one aspect of similarity or difference of two profiles. A suitable metric of difference should be also sensitive to shape, rather than simply to spatial difference.

The method of analysis using curvature values produces a pattern of concavity and convexity corresponding to the clinical perception of the profile, and gives a valuable shape description as one is able to quantify whether the segment has altered its curvature.

Further studies are now necessary to explore the usage of the methods described. Special attention should be given to the classification of the profile segments and to the possible correlation between the various methods. It should be possible to present some parameters that would classify the different facial features. For example, within the segment that represent the nose one might be able to characterize two or three types by considering the length of the spine, or the curvature of the tip of the nose, or even its alar base. Also some measure of the error on this classification should be provided, for a better evaluation of the techniques involved .

VI - References

F. Mokhtarian and A. Mackworth, Scale-Based Description and Recognition of Planar Curves and Two Dimensional Shapes, *IEEE-PAMI* **8** (1986) 34–43.

A.C. Tan, R. Richards and A.D. Linney, The MGI Workstation: An Interactive System for 3D Medical Graphics Applications, *CAR'91*, Springer-Verlag, Berlin, (1991) 705–710.

J.P. Moss, A.D. Linney, S.R.Grindrod and C.A. Mosse, A Laser Scanning System for the Measurement of Facial Surface Morphology, *Optics and Lasers in Engineering* **10** (1989) 179–190.

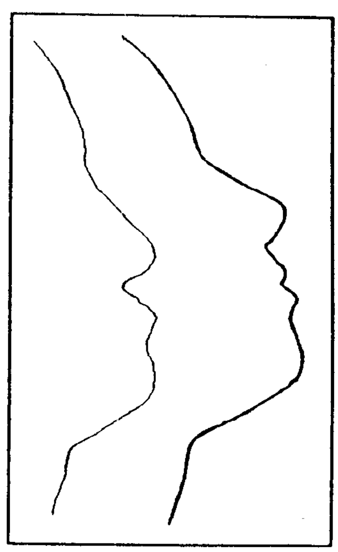

Figure 1 - Mid-line profiles: pre-surgery(left) and post- surgery(right).