Exploratory Analysis of Facial Growth

R. J. Morris[1], J. T. Kent[1], K. V. Mardia[1], R. G. Aykroyd[1],
M. Fidrich[2], A. Linney[3]

[1] Department of Statistics, University of Leeds
[2] Artificiel Intelligence Group, Jozsef Attila University, Hungary
[3] Medical Graphics and Imaging Group, University College London

1 Introduction

In this paper we will compare two methods for analysing growth of faces. We will concentrate on on the shape and size of the profile of the face. The two methods differ in the way that the individual profiles are registered. In the first method Generalised Procrustes Analysis is used to register the profiles. This technique can cause some errors due to mis-registration. In the second method the profiles of each individual are registered together using the Iterative Closest Point Algorithm (ICP) (Besl and McKay, 1992). See Morris *et al.* (1999) for fuller details of the algorithms discussed here.

We have obtained a set of laser scans (Moss *et al.*, 1989) from a number of individuals with between two and eight scans per subject taken at ages between 5 and 15. Each scan consists of about 30,000 3D points arranged as a mesh of quadrilaterals. For the purpose of this paper we do a preliminary analysis of the scans of five individuals (a total of 28 scans in all).

2 Extracting the Profile and Defining Landmarks

Both methods share a common way of extracting the profiles from the 3D datasets and calculating landmarks on the profiles.

First the *medial plane* of a head is found. This is the plane which runs vertically down through the nose separating the left and right sides of the head. We use a version of the Iterative Closest Point algorithm (ICP) to find a plane such that the reflection in that plane matches the left side of the head onto the right side.

Once we have found the medial plane the head is rotated so that the medial plane becomes the plane $z = 0$. The profile is then extracted by calculating the boundary of the shadow cast by light rays parallel to the z-axis onto a plane parallel to $z = 0$ lying entirely behind the surface.

A hierarchical scheme based on bi-tangents and distances from lines is used to calculate a set of landmarks on each profile. First the bi-tangent lines connecting the forehead and nose and the nose and chin are found. The four points of bi-tangency are connected by three line segments. For each segment those points on the profile which are local extremals of distances from the line (both maxima and minima) are found. This strategy

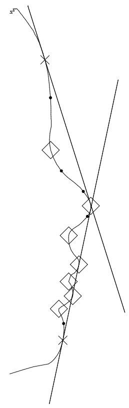

Figure 1: Constructed landmarks: $\times$ indicates bi-tangent landmarks, $\diamond$ indicates first stage landmarks and $\bullet$ indicate second stage landmarks. The two bi-tangent lines are also shown.

(a) First method (b) Second method

Figure 2: The registration of three profiles produced by the two methods.

gives points at the top, bottom and tip of the nose, points on the top and bottom lips, a point between the lips and one between the lower lip and chin. We call these *first stage landmarks*. The process is then repeated for the line segments joining successive bi-tangent points and first stage landmarks. The points at maximal distances from these segments are called *second stage landmarks*. These gives us more detail for the forehead and nose. Finally we thin out some of the artificial extrema by hand to get a set common to all subjects. This set is shown in figure 1 and consists of 14 landmarks.

3 Analysis using Procrustes registration

Our first method of registering the profiles uses Procrustes analysis (Dryden and Mardia, 1998; Kent, 1994) to produce a representation of the size-and-shape of each profile. This representation is independent of the rotational and translational components of the original profiles. We obtain a set of *Procrustes tangent coordinates* $\{\mathbf{u}_i \in \mathbf{R}^{2k-3} : 1 \leq i \leq n\}$ where $k = 14$ is the number of landmarks on each profile and $n = 28$ is the number of profiles. The first $2k-4$ elements of each vector represent the shape and the last element is the logarithm of the centroid size.

The tangent coordinates are grouped by subject and the within group covariance matrix calculated. The eigenvectors of this matrix are used as the basis for the Principal Component Analysis. In practice we found there was little difference between using within-group covariance matrix and the full covariance matrix. The age ranges of the subjects are all different so there is a considerable component of growth exhibited between the groups. For this reason we use the raw Procrustes tangent coordinates, rather than coordinates centred for each group, when calculating the principal component scores. The first principal component (PC) was found to account for 70 percent of the total variability. and there is a strong correlation of 0.84 between age and the first PC score. Figure 3 shows the first and second principal component scores for each profile. The lines connect the different profiles for the same person at successive ages, and the number by each point is the age. In all there are five subjects with 3, 4, 6, 7 and 8 scans respectively.

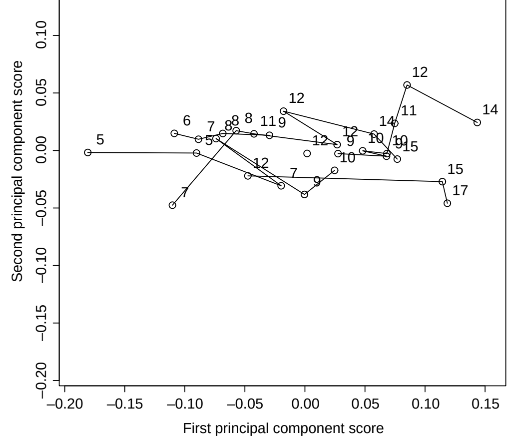

Figure 3: The first and second principal component scores for size-and-shape using the first method. The lines connect the profiles of each subject.

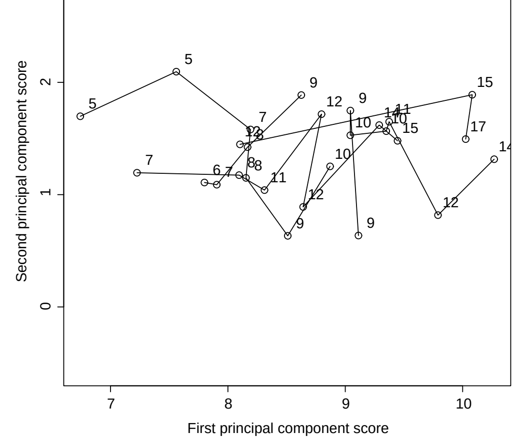

Figure 4: Principal component scores using the second method.

Note how there is some backtracking in the first principal component score. Ideally this score would increase monotonically with age. Figure 2a illustrates the cause of this backtracking. The three profiles in the figure show the same individual at increasing ages. The profiles are registered fairly well but there is some shifting in the vertical direction. In one of the scans the individual held his mouth tightly closed which raised the chin. As some of the landmarks are on the chin this has the effect of raising the centre of the configuration of landmarks and hence lowering the registered version of the profile. The degree of mis-registration of this profile is of the same order of magnitude as the total variation between ages.

4 Registration on Foreheads

To overcome the mis-registration problem we exploit the fact that there is little change in the forehead of a person after the first few years of life. Hence it is a good candidate for a basis for registration.

The ICP algorithm is used to register pairs of foreheads. This minimises the distance of the points on one forehead to their closest point on another. It optimises over the set of translations and rotations in an iterative fashion. This technique is very sensitive to the vertical component of the starting point. The ICP algorithm will quickly find a good match in the horizontal direction but not in the vertical direction. This is because the forehead is approximately a vertical straight line and there is little information to pull the registration up or down. To deal with this problem the ICP algorithm is run for a large number of starting transformations each with a different vertical shift. The transformation with the smallest least squares error is used to register the two profiles.

For a sequence of profiles from the same subject with increasing ages we register each adjacent pair and take the cumulative transformations to produce a registration for the entire sequence. Part of such a sequence is shown in figure 2b. We can see that the registration from this sequence is much better than that obtained earlier. The mean profiles for different subjects are registered using Procrustes analysis.

Once we have registered each set of profiles we can again find landmarks and use within-individual PCA to examine size-and-shape information. This gives a slightly better correlation with age of 0.85. There is also less backtracking in the plot of the first two principal component scores, figure 4. The variation between the two plots of PC scores shows how sensitive the algorithm is to finding a good registration.

5 Conclusions

We have discussed two ways for representing the size-and-shape of the profile of the human face and a method for analysing its growth. The results show that a large proportion of the change in size and shape with growth can be explained by the first principal component.

Both methods of registration give us similar results. The registration of the second method looks better visually but this is not reflected by a significantly better correlation with age.

Our current model has so far only looked at a simple one dimensional model of growth. Further work is needed to take account of the differences between male and female faces, the differences between the major facial types, and the variations, with age, in the rates of growth of different parts of the face. In particular, there is a need for better methods for the quantification of shape change. More work is also needed in identifying the source of errors, whether they are due to measurement, facial expression or inaccuracy in landmark selection.

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