Facial image comparison using 3D techniques

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Abstract

In forensic comparison of facial images, preferably reference images are used in which the head is positioned corresponding to the disputed facial image. 3D imaging techniques, together with 3D modeling software, offer the possibility of flexible and reproducible positioning of the head of a person corresponding to the face and camera position of the 2D facial images. We performed an analysis of 3D data from the facial area of 3D whole body scans to find the landmarks that are best suited for automated facial comparison. Eight facial landmarks were manually annotated, and recorded in the scanning process. We measured the absolute distances between these landmarks in the 3D models.

To find a measure of the discriminating value of the distance measurements, we calculated the probability that the measurements of two subjects are not significantly different. If the measurements of a subject are close to the mean (i.e. a 'common' face), there is a probability that the same measurements are found in one of two subjects of the present data. If the measurements of a subject are in the tail of this distribution (i.e. a rare face), the probability that the same measurements are found on another subject is one in twelve subjects. The data set was not geared towards facial recognition however, and used a relative low-resolution scanning system. Therefore, we are currently studying the discriminating value of distance measures in a data set scanned at much higher resolution.

Introduction

In forensic comparison of a facial image with the face of a suspect, preferably reference images are used in which the head is positioned corresponding to the disputed facial image. Techniques using three or more landmark points on the face have been proposed for matching the face and camera positions to the available photographs [1]. However, these methods can be cumbersome, and require the cooperation of the suspect.

3D imaging techniques, together with 3D modeling software, offer the possibility of flexible and reproducible positioning of the head of a person corresponding to the face and camera position of the 2D facial images. Lately, 3D facial models can be more easily acquired since acquisition techniques have been improved. Therefore, some face recognition methods have been extended for 3-dimensional purposes. Using 3D models one can deal with one main problem in 2D face recognition; the pose of the head. Also the surface curvature of the head can now be used to describe a face.

However, a recent study [2] has shown that although useful for positioning, matching of a 3D model with a 2D image cannot be reliably used for identification based on match-point distance statistics. One of the remaining issues in matching 2D images with 3D models is the correct positioning of reference points by the investigators. To study the possibilities of automating the positioning of landmarks, we performed an analysis to find the landmarks that are best suited for automated facial comparison.

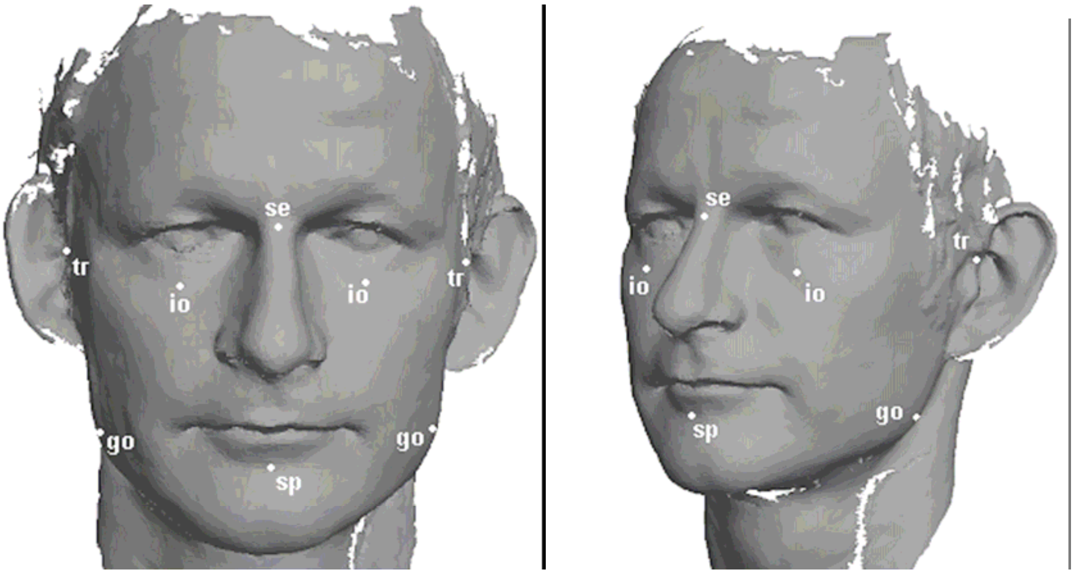

Figure 1: The positions of the facial landmarks of the CAESAR-survey. These landmarks are manually located.

Materials and Methods

For this study we used the whole body scans of the Dutch and Italian parts of the CAESAR (Civilian American and European Surface Anthropometry Resource) survey [3]. The main goal of the CAESAR-survey was to acquire 3D whole body scans of 5.000 subjects. It took place from December 1997 until December 2001 in America, Italy and the Netherlands. The current study used the 3D body scans of 1127 subjects made in the Netherlands, and 793 scans made in Italy. In the Netherlands a Vitronic 3D body scanner was used to generate the 3D data [4]. In Italy the 3D whole body scans were acquired using a Cyberware 3D body scanner [5]. Of a subset of 20 people in the Netherlands, 18 repeat scans (9 with the Vitronic scanner and 9 with the Cyberware scanner) were made to determine intra-subject variability.
For the data analysis and the 3D face recognition problem we extracted the facial region from each whole body scan using bounding boxes as described in [6]. In this facial region 8 landmarks were defined by the CAESAR-survey:

- *Sellion* (**Se**). Point of greatest indentation of the nasal root depression.
- *Right Infraorbitale* (**r Io**). Lowest point on the inferior margin of the right orbit, marked directly inferior to the pupil.
- *Left Infraorbitale* (**l Io**). Lowest point on the inferior margin of the left orbit, marked directly inferior to the pupil.
- *Supramenton* (**Sp**). Point of greatest indentation of the mandibular symphysus, marked in the midsagittal plane.
- *Right Tragion* (**r Tr**). Notch just above the right tragus (the small cartilaginous flap in front of the ear hole).
- *Left Tragion* (**l Tr**). Notch just above the left tragus (idem).
- *Right Gonion* (**r Go**). Inferior posterior right tip of the gonial angle (the posterior point of the angle of the mandible, or jawbone).
- *Left Gonion* (**l Go**). Inferior posterior left tip of the gonial angle (idem).

The gonion is difficult to find when covered with a lot of tissue.

To indicate the landmarks on the head during scanning, white stickers were used with a diameter of 1 cm. Picking the landmarks in the data set was performed semi-automatically. A program identified the locations of the landmarks based on the white color of the stickers. These locations were presented to the observer to annotate the accurate location in the landmark file. The locations of the landmarks are shown in figure 1.

Results

We determined the absolute distances between the above landmarks in the 3D models. Two datasets were analyzed separately: one dataset with 18 repeat scans from 20 people, and a dataset from scans from 1920 people. From the data set with repeat scans the mean standard-deviation of the measurements per subject was determined (intra-subject variation), as well as the (overall) standard deviation (inter-subject variation), see Table 1. As can be seen, the 20

	Mean standard-deviation per subject	Mean (N=20)	SD (N=20)	Mean (N=1920)	SD (N=1920)
Se_Sp	2.6	97.1	5.8	96.4	7.4
Se_lTr	3.4	117.7	3.8	118.8	7.2
Se_rTr	3.0	124.1	4.8	121.7	7.3
Se_lInfr	2.2	44.7	1.9	45.7	4.9
Se_rInfr	2.1	47.1	2.9	46.2	4.6
Se_lGo	3.2	135.7	7.0	131.6	9.9
Se_rGo	3.0	141.0	7.2	135.6	9.8
rInfr_lInfr	3.2	66.4	3.1	66.8	5.5
rInfr_rTr	3.0	92.6	4.5	90.0	5.9
rInfr_Sp	2.6	76.8	4.5	77.2	6.4
rInfr_rGo	3.2	103.3	7.3	96.9	8.0
lInfr_lTr	3.6	86.8	3.6	85.5	5.9
lInfr_lGo	3.8	98.3	6.6	91.3	8.3
lInfr_Sp	2.6	77.9	4.5	77.9	6.3
Sp_lTr	3.2	135.9	5.1	136.6	8.4
Sp_rTr	3.2	140.4	6.0	137.8	9.0
Sp_lGo	3.7	105.3	6.4	98.4	8.4
Sp_rGo	3.6	107.8	7.1	100.8	8.8
rTr_rGo	2.7	68.4	5.6	67.9	9.2
lTr_rTr	2.2	144.7	4.4	148.0	8.4
lTr_lGo	3.1	63.5	5.4	66.6	9.4
rGo_lGo	4.0	111.5	9.5	118.2	11.0

Table 1: Mean distance between landmarks, mean standard-deviation of the distance per subject (intra-subject variation) and (overall) standard deviation (inter-subject variation) of landmark distances for the full test-set (N=1920) and a subset (N=20) for which repeated measurements were made.

subjects sample is reasonably representative for the larger sample. Also can be seen that the intra-subject variation in this data set is about half the inter-subject variation.

To find a measure of the discriminating value of the distance measurements of the CEASAR data, we calculated the probability that the measurements of two subjects are not significantly different. We assumed that the measurements for all subjects are normal distributed. A problem with the distance data is the high correlation between different distance measures.

order	distance	Estimated LR 'mean'	Estimated LR '5%'	variance explained
1	Se - Sp	2.8	19.4	1.000
2	l Tr - r Tr	3.8	26.1	0.994
3	Sp - r Tr	2.8	19.2	0.837
4	Se - r Tr	2.4	16.6	0.695
5	r Io - r Tr	2.0	13.4	0.615
6	Se - r Io	2.2	15.0	0.573
7	Sp - l Tr	2.6	17.9	0.402
8	r Io - Sp	2.5	16.8	0.346
9	Se - l Io	2.2	15.2	0.329
10	r Io - l Io	1.7	11.7	0.205
11	l Io - Sp	2.4	16.5	0.092
12	Se - l Tr	2.1	14.5	0.090
13	l Io - l Tr	1.6	11.2	0.086

Table 2: The results of the stepwise discriminant analysis for the landmark set without the gonion.

For individualization of subjects based on the facial distances, the most identifying distances should be used. To study this problem we used stepwise linear discriminant analysis (LDA). For this analysis we used the same dataset as for the analysis above. The results of the analysis are displayed in figure 2(a) for the landmark set with the gonion and in figure 2(b) for the landmark set without the gonion. In the second set the gonion was excluded, because this landmark is hard to determine accurately based on the facial scans only, and this is the material available for most 3D facial comparison cases. The order of the selection of landmarks for the landmark set without gonion, the estimated LR of each distance, and the

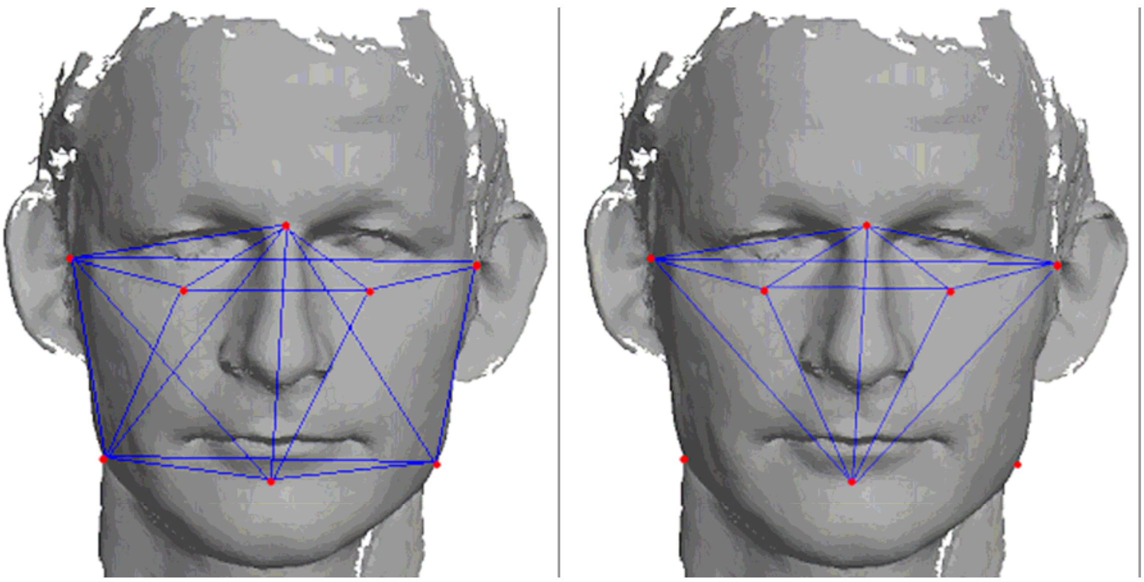

Figure 2 : The landmark sets resulting from the stepwise linear discriminant analysis *when started with the complete candidate set (a) and with the candidate set without the distances from and to the gonion (b).*

fraction of explained variance by each distance are shown in Table 2. Using these data, an estimate of the LR of finding the same measurements as those of an 'average' (circles) face can be made, depending on the measurement error (Figure 3, dashed line).
Another way of estimating the LR of the set of distances was presented by Helmer [7]. He presented a study of the discriminating value of a set of measurements on human skulls. He defined a probability *p(s)* that another skull can be found with the same measurements. In this analysis the complete covariance matrix of the dataset was included. With the probability of finding measurements of a skull at hand being one, *1/p(s)* is equivalent to the Likelihood Ratio (LR), a number indicating the evidential value of an observation. Also with Helmer's formula, it is possible to make estimates of the LR of facial measurement sets. Figure 3 shows the LR values of the dataset depending on the measurement error (closed symbols).

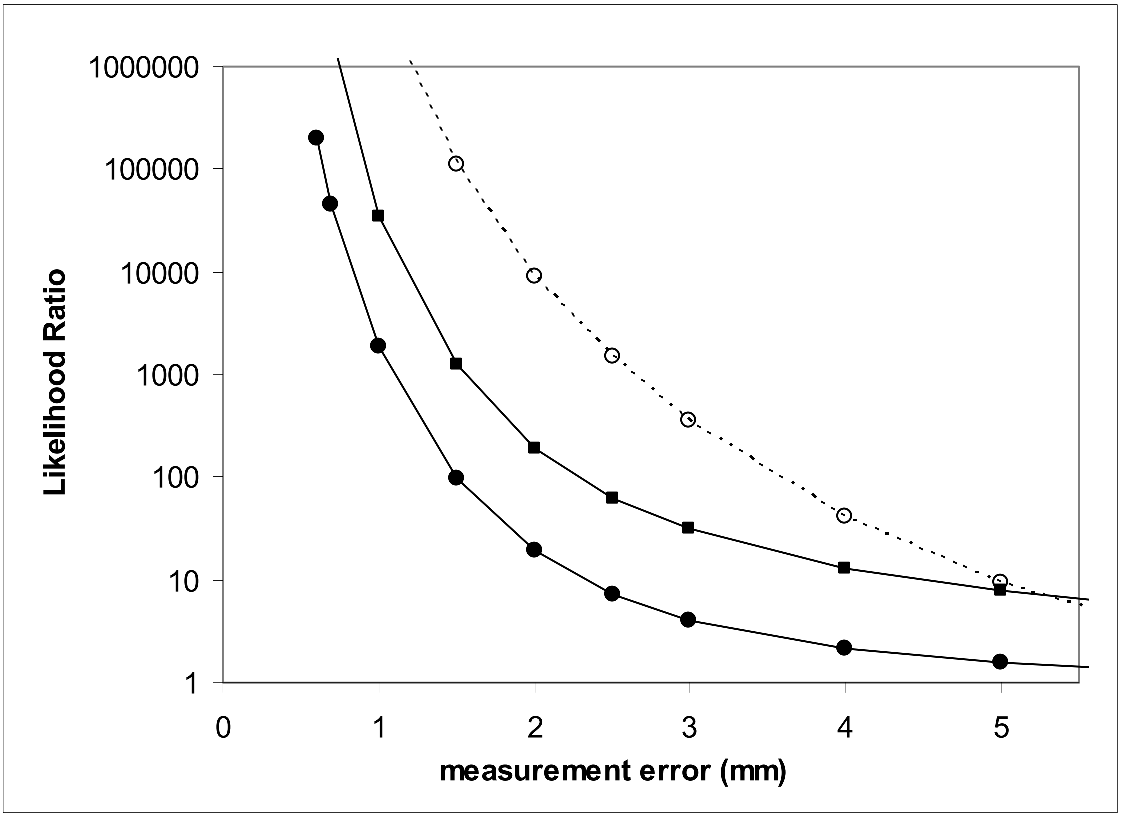

Figure 3: Estimates of Likelihood ratio of finding the same measurements in an average' (○,●) or 'rare' (■) face and in a random person of the rest of the sample, as a function of the measurement error, using stepwise LDA (open symbols) or Helmer's formula [6] (closed symbols).

Conclusions

To find a measure of the discriminating value of distances between landmarks on the face, we calculated the probability that the measurements of two subjects in the CEASAR data set are not significantly different. We focused on the dataset without the gonion, because this landmark is hard to detect in facial images. Two models were used to estimate the likelihood ratio of de distance measures: LDA, and Helmer's formula. The LDA model resulted in more optimistic LR numbers than Helmer's formula by a factor of 10-1000 for measurement result

on an ‘average’ face. However, the message of both models is the same: in the range of measurement errors to be expected in facial comparison image material, i.e. in the range of 1-5mm, the LR is highly dependent on the measurement error.
The CAESAR data set was not geared towards facial recognition however, and used a relative low-resolution scanning system. Therefore, we are currently studying the discriminating value of distance measures in a data set scanned at much higher resolution.

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