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TECHNICAL NOTE

GENERAL

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A View to the Future: A Novel Approach for 3D–3D Superimposition and Quantification of Differences for Identification from Next-Generation Video Surveillance Systems*

ABSTRACT: Techniques of 2D–3D superimposition are widely used in cases of personal identification from video surveillance systems. However, the progressive improvement of 3D image acquisition technology will enable operators to perform also 3D–3D facial superimposition. This study aims at analyzing the possible applications of 3D–3D superimposition to personal identification, although from a theoretical point of view. Twenty subjects underwent a facial 3D scan by stereophotogrammetry twice at different time periods. Scans were superimposed two by two according to nine landmarks, and root-mean-square (RMS) value of point-to-point distances was calculated. When the two superimposed models belonged to the same individual, RMS value was 2.10 mm, while it was 4.47 mm in mismatches with a statistically significant difference ($p < 0.0001$). This experiment shows the potential of 3D–3D superimposition: Further studies are needed to ascertain technical limits which may occur in practice and to improve methods useful in the forensic practice.

KEYWORDS: forensic science, forensic anthropology, forensic anatomy, personal identification, video surveillance system, stereophotogrammetry

In forensic anthropology, identification of persons filmed by video surveillance systems is becoming more and more relevant and brings new challenges for what concerns the correct recognition of the suspect (1). Several approaches at personal identification from video surveillance systems have been developed by literature, mainly based on the morphological assessment of facial traits and metrical analysis of facial proportions (2). The former methods are performed through the classification of facial traits according to atlases, but are severely influenced by a relevant interobserver and intra-observer error, which often renders a facial assessment not reproducible (2); in addition, they bring about limits for what concerns the quantification of results as literature often does not report precise error rates (3).

On the other side, the metrical approach is based on indices measured on the images: however, procedures for metrical comparison of faces are not standardized in literature (2), and literature on this topic deals with small samples (4). In addition, facial metrics prove to be strongly affected by quality, resolution, and distortions of the image: Therefore, caution is suggested in achieving identification from metrical features of faces (2).

Another approach derives from the superimposition of images, for example, of pictures taken from video surveillance systems and photographs of suspects: However, this type of procedure brings about limits concerning difficulties in replicating the orientation of the face as observed in video surveillance records (2). Form this point of view, the most advanced approach to the complex topic of identification of the living consists in the 2D–3D superimposition, where the 3D model is superimposed on the 2D image of the suspect extracted from the video surveillance films (5). This method allows the operator to reduce to a minimum the bias due to the different head position and to provide a reliable comparison between the facial outlines (6); in addition, it is more promising than the morphological comparison of faces, which proved to be affected by subjective opinion of the observer (7) and the metrical analysis (8).

In addition, 2D–3D superimposition should consider the problems of final judgment concerning positive or negative identification and the quantification of the error: Yoshino et al. (9) investigated linear distances between facial landmarks and reported that the mean distance obtained from 16 reciprocal point differences and the percentage error at the false positive/negative crossover threshold were, respectively, 3.1 mm and 4.2%. In detail, for superimposition between a photograph and a 3D model of the same person, the mean distance was between 1.4 and 3.3 mm, whereas it was between 2.6 and 7.0 mm in case of mismatches. As one can observe, the two ranges show

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an area of superimposition: From this point of view, the linear assessment of facial landmarks does not provide a conclusive indication concerning the match between the photograph of the suspect and the 3D model of a person in custody, as in some cases the chosen method may give an ambiguous result. In other words, the mean distance between corresponding landmarks in cases where the 3D scan and the photograph belong to the same individual partially overlaps with the same parameters in cases where the 3D scan and the photograph belong to different subjects. Further studies have also pointed out the limited reliability of the linear metric approach in homozygous twins and in cases of emotional expressions; on the other hand, facial aging seems not to affect the method (10).

Other attempts at quantifying identification have focused on the 2D–3D superimposition in a profile view: Results showed that the difference in area between the 2D and 3D profile of the same individual is between 43 and 133 mm^2, whereas in mismatches, the same value was always higher than 157 mm^2 (11). In this case, metrical parameters measured in matches and mismatches do not overlap: However, the reliability of results is limited by the low number of superimpositions, and the obtained thresholds can be applied only to a very specific position of faces, not always observed in practice.

The issue of quantification and ascertainment of the identification judgment has still a relevant importance and will be expanded by the contributions given by modern technology. In recent years, the chance of developing 3D video surveillance systems, able to obtain a 3D model of the suspect, has increased the chances of a more valid identification (12). These novel techniques are usually based on the use of different cameras focusing on the same area (12) and the integration of data from different cameras located in the same room (13). Although the application of such systems is still at the beginning and is mainly limited to the assessment of the track and posture of represented people, they are the first attempt at a complete 3D registration of subjects. In the next future, the introduction of such technology may allow the operators to perform 3D–3D superimpositions with a clear increase of information useful for reaching a conclusive judgment. From this point of view, the application of 3D–3D superimposition promises interesting chances of overcoming the current limits concerning the probability of correct identification; however, at the moment, the experiments of 3D–3D superimposition are limited to three-dimensional models acquired by radiographic imaging techniques and usually concern treatment of dental malocclusion (14–18). At the present, no study concerning the identification potential of 3D–3D superimposition has been published.

This study aims at proposing a novel method of superimposition between 3D models of faces and quantification of differences, useful for a possible judgment in identification applicable to modern technologies of 3D video surveillance systems. A first application on a selected group of adult subjects is also presented.

Materials and Methods

The experimental project was performed on 20 male adults, aged between 32 and 39 years, without facial deformities, pathologies, or signs of previous surgery. An informed consent was given by every subject. An optical three-dimensional model of the facial surface of each man was obtained twice by a stereophotogrammetric device (VECTRA-3D® M3: Canfield Scientific, Inc., Fairfield, NJ) (19). Geometry resolution of Vectra 3D M3 is 1.2 mm (triangle edge length), as reported by the technical sheet. The time period elapsed between the two acquisitions went between a few minutes and 67 months. The 3D model focused on the facial oval area included between the trichion, the lower edge of the mandible, and the line between gonion and tragion.

On each 3D facial model, nine landmarks (right and left endocanthion, exocanthion, cheilion: on the midline, sellion, pronasale, and subnasale) were identified using VAM® software (Canfield Scientific Inc., Fairfield, NJ) included in the stereophotogrammetric device (20); the first acquisition of each individual was then superimposed to the first model of all the other subjects taking part in the project (Fig. 1). The superimposition was performed to reach the best match between the corresponding landmarks. The same procedure was performed also between the two models taken from the same individual. Where the two superimposed images belonged to different persons, comparisons were considered as mismatches: On the other hand, comparisons of models from the same individuals were considered correct matches. In total, 210 superimpositions were performed. In detail, after the faces had been superimposed according to the reference landmarks, the VAM® software was requested to register the two surfaces to obtain the chromatic map of facial modifications, and it calculated the root-mean-square (RMS) and mean values of point-to-point distances between the two models (Fig. 2).

Mean distances between the points of two models and RMS values were evaluated by Student's t-test ($p < 0.05$).

In addition, for 10 comparisons, the positioning of landmarks and the assessment of mean distance and RMS were repeated 6 months after the first evaluation. Differences between the two observations were statistically analyzed by Student's *t*-test ($p < 0.05$).

Results

Result from intra-observer assessments did not show statistically significant differences ($p > 0.05$). Results from correct matches and mismatches are reported in Table 1 and Fig. 3. The results highlighted differences between the two groups: In cases of mismatches, the mean distance ranged between 0.02 and 5.09 mm, whereas in cases of correct matches, the same interval was between 0.01 and 0.94 mm. Figure 3 shows the dispersion

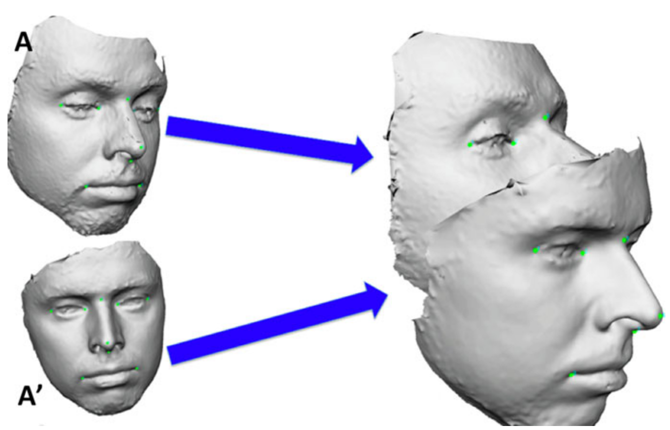

FIG. 1—*Collocation of nine facial landmarks on the two 3D facial models (A and A') and superimposition. [Color figure can be viewed at wileyonlinelibrary.com]*

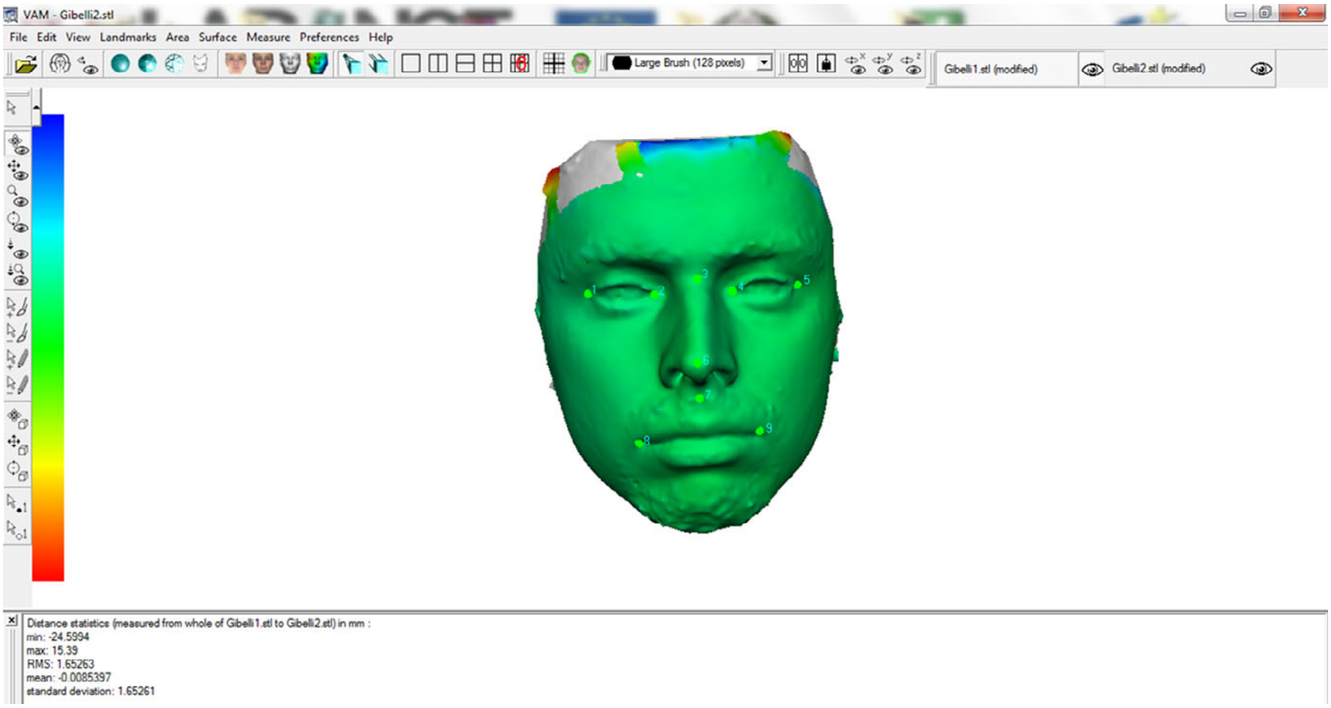

FIG. 2—*Final result of the superimposition of two models with calculation of RMS value. [Color figure can be viewed at wileyonlinelibrary.com]*

TABLE 1—*Mean value and root-mean-square (RMS) of point-to-point distance between the superimposed models taken from the same individuals (correct matches) and from different individuals (mismatches).*

		Mean Distance (mm)*	Root-Mean-Square (mm)*
Mismatches (no. 190)	Mean	1.68	4.47
	SD	1.25	1.55
Correct matches (no. 20)	Mean	0.44	2.10
	SD	0.31	0.90

*Statistically significant differences, Student's *t*-test ($p < 0.0001$).

of RMS in the 210 different observations: as one can observe, correct matches were gathered in low RMS areas, whereas mismatches were found in areas with high RMS level and showed more variability.

When the two superimposed models belonged to the same individual, mean distance and RMS value were, respectively, 0.44 and 2.10 mm, whereas the same values were 1.68 and 4.47 in cases of mismatches. The difference between the mean and RMS results obtained in the two groups was statistically significant ($p < 0.0001$).

Discussion

Identification of the living is a very specific field of application of forensic anthropology for a number of reasons: first, it concerns mainly the assessment of morphology, which necessarily uncovers the problems of quantifying a conclusive judgment, as observed also in other anthropological issues, such as the identification of the dead from bone features. Second, identification from video surveillance images is strictly linked to technological development, and therefore, the error ranges and reliability of anthropological methods of comparison depend upon the type of information made available by the acquisition techniques.

The actual methods of 2D–3D superimposition show relevant problems concerning the exact distinction between positive identification and negative identification, which increases the difficulties linked to the low resolution and quality of images usually extracted from video surveillance devices.

From this point of view, the 3D–3D superimposition seems promising as it provides a more complete and adherent superimposition between the suspect and the person in custody; this study aimed at providing an example of a protocol for superimposing 3D models, based on nine facial landmarks. The landmarks were chosen among those with lowest interobserver and intra-observer error (21), to reduce the possible bias of identification and positioning. The protocol proved to adequately distinguish between superimposition of models from the same individual and from different subjects: both the mean distances between the points of two models and RMS values were highly different passing from correct matches to mismatches, and the differences were statistically significant.

An interesting point to discuss is the superimposition area between matches and mismatches, which was observed also by Yoshino et al. (9) who applied the assessment of distances between corresponding landmarks in 2D–3D superimpositions. From a general point of view, the superimposition between matches and mismatches may result in a high distance between the 3D scans from the same individual and/or a small distance between 3D scans from different individuals. The former case may be due to a possible change of facial shape between the acquisitions of the two 3D models, for example, due to weight modifications: In fact, the time period elapsed between the two acquisitions in some cases reached several months. In addition, the possible presence of slight modifications in the degree of facial muscular contraction between the two scans may have a role in determining a high difference between the 3D scans

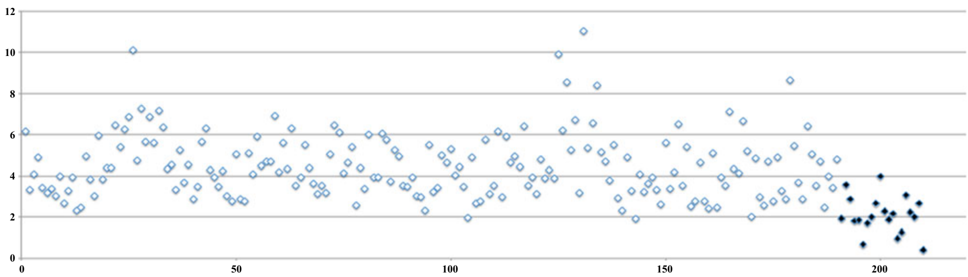

FIG. 3—*Dispersion of observations according to RMS of point-to-point distances, divided between mismatches (white point) and correct matches (black point). [Color figure can be viewed at wileyonlinelibrary.com]*

belonging to the same individual. Literature in fact highlights that involuntary facial movements do introduce an additional error in comparing 3D facial scans, also in rest position (22,23).

The latter case may be due to a resemblance in facial shape between two different individuals, which actually is the most relevant error which may occur in procedures of comparisons, as it leads to false positive identifications. Indeed, the 20 men analyzed in the current study did not show an evident resemblance among them, although some superimposition between 3D scans belonging to different individuals shows RMS values similar to those reported by matches. The relation between the morphologically visible resemblance which may be felt by direct observation and such metrical resemblance still needs to be analyzed in depth and represents an interesting hint for the future studies.

The novel procedure clearly opens wide possibilities of a more precise identification with the introduction of more advanced methods of scene acquisition, although several limits still need to be overcome. First, the present study took into consideration 3D models created *in vivo* in standard conditions, and none of them was obtained by a 3D video surveillance device. From this point of view, the practical application of such methods is still to be verified, especially for what concerns the quality of the 3D models. For this reason, the present results need to be confirmed by applying the protocol to a larger sample and in nonideal conditions.

In addition, the novel perspective of 3D–3D comparisons requires verification of the influence of variables which have been widely studied in cases of 2D–3D analysis, such as facial mimicry and the possible presence of disguised faces. Emotional expressions proved, as shown by literature, to strongly affect the reliability of the traditional 2D–3D superimposition (10); the introduction of 3D methods of acquisition provided new possibilities for the analysis of three-dimensional changes to different facial movements (24). However, the possible impact of such modifications on future 3D–3D comparison still needs to be verified.

Disguised faces as well may provide additional difficulties for personal identification based on facial comparison: Yoshino et al. (25) took into consideration the presence of camouflages in cases of 2D–3D superimposition and found that even when faces were not completely visible cases of correct matches and mismatches did not overlap. However, this type of study needs to be replicated also in 3D–3D cases to verify whether the lack of detectability in some facial portions may reduce the reliability of superimposition methods. The next studies will focus on the impact of such factors on possible 3D–3D methods of identification.

This study takes into consideration the 3D–3D superimposition procedures from a theoretical point of view: therefore, some limits have to be considered. For example, the main issue concerns technical limits which will derive from the practical application of such procedure. The first problem is the need of creating a 3D model from multiple cameras and the consequent error. Clearly, the elaboration of the 3D model for superimposition will necessarily modify also the results which may be obtained from the procedure. However, the first step was to verify whether 3D–3D superimposition is worth being taken into consideration for personal identification. Although one may intuitively think that 3D models of faces are more descriptive than the correspondent 2D images, however, a quantitative assessment in cases of matches and mismatches is worth being performed. The present study highlights that 3D–3D superimposition may give relevant information for personal identification.

For the same above-mentioned reasons, the description of a cutoff threshold for differential diagnosis of positive identification could not be considered. In the present article, the small sample size prevents from drawing up any quantitative indication. In addition, we have to consider that the practical application of 3D–3D superimposition is still limited to a theoretical context: technical limits which may affect the practical application of such procedure have still to be analyzed in depth. Further studies on larger samples and the progressive introduction of 3D–3D superimposition methods will enable the researchers in establishing threshold values for positive identification, as observed in 2D–3D techniques (9).

In conclusion, this pilot study shows that identification based on 3D–3D superimposition may be reliable in best case scenarios (high-resolution acquisitions, good homology between the two models, and for entire faces), although it needs to be further tested to verify its applicability to the forensic practice. This may be a useful starting point for standardizing methods of identification of the living in the next future provided that 3D surveillance systems become more popular.

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