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A new three-dimensional photogrammetric face scanner for the morpho-biometric 3D feature extraction applied to a massive field analysis of Italian attractive women

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Abstract

The authors developed a method and a specific photogrammetric 3D scanning equipment for acquiring, analyze and measure the characteristics of the facial soft tissues. The system can be used in anthropometry and for the diagnosis and monitoring of therapy for maxillofacial surgery and for orthodontics. The experiments were conducted on a sample composed of 66 female subjects (64 Caucasian, 1 Ethiopian, 1 Brazilian) finalists at an Italian national Beauty competition done in the year 2010. The subjects were submitted on the same day to the acquisition of faces, according to a new clinical protocol.
Morphometric characteristics of the faces were investigated extracting linear measurements, angles, distances and relationships between angles, calculated thanks to the measurement of facial soft tissue landmarks, through which it is possible to reconstruct simplified volumetric models of faces for each candidate. These data were compared with the historical ones available in literature.
Performing a statistical analysis on the average values of the samples it was possible to obtain a very interesting indication of which facial parameters are related to facial attractiveness that diversify more different samples of attractive girls. An objective was to identify the aesthetic canons in the form and dimensions of the face of the 66 subjects. The protocol standardization has made it possible to carry out the relief of the sample recreating for all subjects scanned the same conditions in a reliable and fast way.
The developed scanner confirmed to be precise for measurements, robust, fast in the relief, easy in the scanning operations, and furthermore it is portable, it has a low weight, low cost, being also completely non-invasive.

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Keywords: facial scanner; photogrammetry; anthropometry; attractiveness

1. Introduction

Thanks to the availability of new measurement systems, new anthropometric studies that consider three-dimensional surfaces were developed [1,2]. Techniques of digitization of the human face must consider various aspects, such as realistic and accurate reproduction of the form obtained, the acquisition time for the model, the simplicity and cost of equipment.

For medical applications, non-contact methods are particularly interesting: the contact with the probe instruments during the measurement of soft tissues can deform the facial surface, and thus can be a source of inaccuracy.

In last years begin to be available on the market some anthropometric equipment dedicated to the detection of the human face [2]. The major limitations of these optical systems are particularly cost, limited portability, and often the difficulty to identify landmarks on the computer reconstruction of the facial surface [3].

Photogrammetry is on the contrary a method definitely cheaper, easy to use and requires a short acquisition time. This technique allows to obtain the spatial position by photos and using a processing software for the image reconstruction [4].

The photogrammetry scanning systems, thanks to the

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large number of anatomical points identified during the acquisition, have proved to be very useful in the morphological study of patients with facial asymmetry, facial clefts or other craniofacial disorders and dysmorphoses: in particular, these systems have proved valuable in providing a detailed morphological analysis of patients with complex facial deformities, since they avoid the distortion and magnification of typical radiographic images.

The used photogrammetric measuring methods do not provide the mechanical contact of the probe with the object: 3D information is obtained through the acquisition and comparison of several photographic images [5]. Multiple synchronized cameras are ideally suited to digitize the human body, for insensitivity to slight movements of the body [6,7].

The acquisition of information by photogrammetric techniques is very fast (4-6 ms). For these performances, the National Institutes of Health Clinical Center decided to use this method for a wide field survey in the United States, Brazil and Peru, on healthy volunteers and patients with craniofacial dysmorphoses [8].

2. Materials and Methods

The authors have developed specific Research Projects of National Interest [9,10,11,12,13,14,15] and they have designed low-cost scanning systems for photogrammetric diagnosis of facial and post-operative analysis. The system used in this research is based on 5 high definition digital cameras DSLR; it has a precision of 0.5 - 0.6 mm on average, and up to 0.03 mm on X and Y and 0.15 mm on Z for individual points measurement with coded target. Recently, the precision of this scanning system was validated using physical specimen (dummies), comparing the results with the ones obtained using a Coordinate Measuring Machine (CMM) [16], obtaining a mean value of 0.42 mm, and a standard deviation of 0.14 mm for the measurement errors.

The set for the photogrammetric scanning system is realized using cold light lamps, flashes, cameras, computer remote control, simultaneous control of the camera (shutter speed data, trigger, recording of images), and a photogrammetric software (Photomodeler^{TM} V6).

The processing allows the precision measurement of anatomical landmarks, the virtual 3D computer reconstruction of faces, and the extraction and calculation of all the features important for the assessment of facial characteristics and attractiveness.

The study sample consists of 60 finalists + 4 reserves subjects competing in the Miss Italia 2010 competition, and the first 2 classified in the Miss Italia 2009 competition. The faces of the subjects were scanned in conditions of no makeup and with their hair behind the head. Before scanning, on the faces of each girl the anatomical landmarks were detected with direct method (inspection and palpation) and were marked by use of hypoallergenic eyeliner (Fig. 1). Each girl was placed in front of the acquisition system taking the natural position of the head (Natural Head Position-NHP) (Fig. 2), keeping the eyes looking to infinity, having a natural expression of the face, with lips and teeth at rest in habitual occlusion (Fig. 3). The time required for the preparation of the face and for 3 photogrammetric scanning was about 3 min in total for each girl. The acquisition took place in Salsomaggiore Terme (I), on August 27 and 28 2010.

Fig. 1. Marking the landmarks

Fig. 2. Photogrammetric scanner

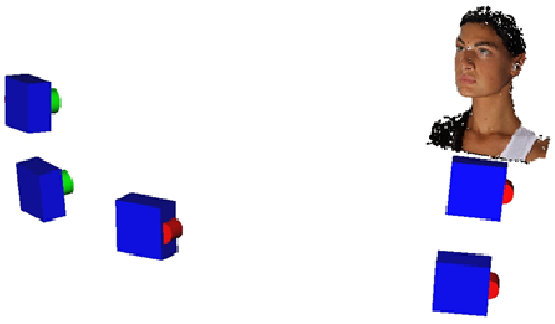

Fig. 3. Diagram of the photogrammetric scanning layout

Literature in the assessments for biometric facial attractiveness is essentially based on the measurement of facial surface points, which are calculated from linear

measurements, angles, distances and relationships between angles, and through which it is possible to reconstruct very simplified volumetric models of faces [17, 18, 19].

The proposed study analyzes the real three-dimensional coordinates of the landmarks indicated in Table 1 and Fig. 4. For each point were calculated also the measurement accuracy for x, y, z, and the accuracy.

Table 1. Landmarks extracted with photogrammetric processing

Points on the midline	Points coupled
Tr - Trichion	Os - Orbitale superius
G -Glabella	Ft – Frontotemporale
N -Nasion	T – Tragion
Prn - Pronasale	Ac - Nasal alar crest
Sn - Subnasale	Chp - Crista philtri
Ls - Labiale superius	Ch – Cheilion
Sto - Stomion	Go – Antegonional
Li - Labiale inferius	C_r - Neck right
Sl - Sublabiale	C_l - Neck Left
Pg - Pogonion	
Me - Menton	
C_c - Neck Center	

3. Results

Starting from the spatial coordinates, 13 measurements of the linear type and 9 of the angular type were calculated (table 2).

The linear measurements are very different, depending on their type and on the girl. The minimum measure value was observed on the Lower lip to E-line distance (*Li-(Prn-Pg)*) that is equal to 0.14 mm, while the maximum value was observed on the Middle facial width (*T_r-T_l*), that is equal to 140 mm.

For each linear measure were calculated uncertainty averages (accuracy), minimums and maximums, as well as the standard deviations and variation intervals (range).

The values for the 13 linear measurements for 66 subjects (858 Data) are shown in table 3. Note that uncertainty adversely affect measures such as the upper facial width (*Ex_r-Ex_l)*, which were marked on images and not directly on the face, the lower facial width (*aGo_l-aGo_r)* and the middle facial width (*T_r-T_l*), in which the marked dots were visible by only two cameras.

Considering only the uncertainty of the measurements for the points on the vertical center, they are much smaller, on average by 0.15 mm (min 0.09, max 0.21, std dev 0.00). For the linear measurements in Figure 5(a) are reported the average values, minimum and maximum, and the standard deviation recorded on the sample.

In Figure 5(b) are shown for angular measurements average values, minimum and maximum and the standard deviation recorded on the sample.

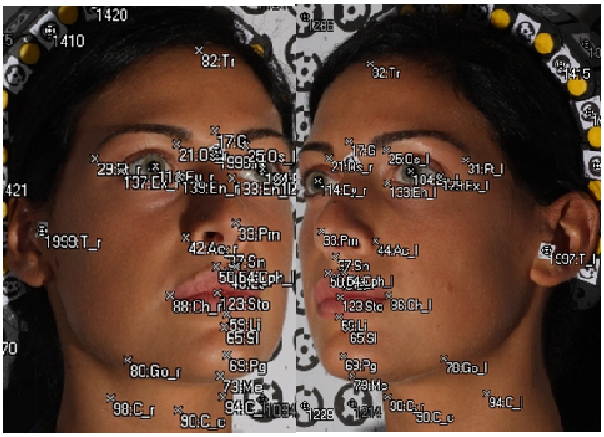

Fig. 4. Landmarks detected

Table 2. Linear and angular measures

Linear measurement	Meaning
N-Pg	facial line
N-M(T_r-T_l)	Nasion – Midpoint of Tragi
Pg-M(T_r-T_l)	Pogonion – Midpoint of Tragi
Pg-M(aGo_l-aGo_r)	mandibular corpus lenght
aGo_l-aGo_r	lower facial width
N-Sn	Anterior upper facial 2° third height
Ch_r-Ch_l	Oral lenght
Ex_r-Ex_l	Upper facial width
Sn-Pg	Anterior lower facial height
T_r-T_l	Middle facial width
Ls-(Prn-Pg)	Upper lip to E-line distance
Li-(Prn-Pg)	Lower lip to E-line distance
Ls-Li	Vermillon height

Angular measurement	Meaning
N-Sn-Pg	Facial convexity excluding the nose
Sl-N-Sn	Maxillary prominence
Prn-Sn-Ls	Nasolabial
(Sn-Ls)^(Sl-Pg)	Interlabial
N-Prn-Pg	Angle among the Nasion-Pronasal and Pogonion
T_l-Prn-T_r	Angles between the Tragi at the level of the Pronasal
T_l-Pg-T_r	Angles between the Tragi at the level of the Pogonion
T_l-N-T_r	Angles between Tragi at levels of Nasion
Sn-N-Prn	Angle among the Subnasal-Nasion-Pronasal

4. Discussion

In the literature there are many articles that report measurements and analyzes of specific groups of attractive girls, compared with the normal population. A very important work was published in 1970 by Peck &

Peck for the analysis of the profiles [20], while Ferrario-Sforza began in 1995 the analysis of faces of attractive women [19], continuing the work with Laino et al [21,22,23,24].

A first question to be answered is whether the samples of attractive women and the reference samples belong or not, with statistical evidence, the same population, or if the differences are such as to assume a population of "beautiful" than the population " normal". This problem can be addressed using the test of t-student coupled for the analysis of the means, if they are available for the samples the values of the averages, standard deviations, and number of samples, assuming a common variance. It is possible to use the student-t distribution with two tails, using:

- *t*: numeric value at which to evaluate the distribution;
- *ng:* number of degrees of freedom;
- The probability P = 1-α,
- n1 = number of units in the first reference sample;
- n2 = number of units in the second reference sample;
- sp = Estimate of the common variance.

It is assumed the difference NS (not significant) if α > 0.05 (probability> 95%). Will certainly be significant differences with α = 0.00 (100% probability).

Ferrario and Sforza in 1995 published data on 10 "beauties" compared with a reference sample of 40 subjects "normal" [19]. Sforza et al [24] published data on 24 "beauty" measured in 2006 compared with a reference sample of 71 subjects "normal", and data on 24 "beauty" measured in 2007 compared with a reference sample of 71 subjects "normal".

Sforza et al [23] published data for 23 attractive girls aged between 13 and 15 years, compared with a reference sample of 51 "normal" subjects. In all the cases, analyzing their data, it can be deduced that there are only some of the measures that differ in such a way as to have statistical evidence of the samples belonging to two different populations.

A summary of the more significant measures for investigations conducted by other researchers is reported in table 4.

A second is whether the measured samples of attractive women in the Miss Italy contest in 2010 (66 subjects) and reference samples taken from researchers mentioned, belong or not, with statistical evidence, to the same population, or if the difference are likely to assume a population of "beautiful Miss Italy 2010" different from populations of "normal" reference subjects. Comparing Ferrario Sforza 1995 [19] and Sforza et al [24] normal reference subjects with Miss Italy 2010 ones, it can be deduced that even in these cases there is a very limited statistical evidence that the samples belong to different populations.

Table 3. Uncertainty average (accuracy), minimum and maximum, standard deviation and variation interval (range) of linear measurements (mm)

Meas.re	Description	Uncertainty	Min	Max	Std Dev	Range
N-Pg	facial line	0.12	0.09	0.14	0.01	0.05
N-M(T_r-T_l)	Nasion - Midpoint of Tragi	0.18	0.08	0.71	0.15	0.63
Pg-M(T_r-T_l)	Pogonion - Midpoint of Tragi	0.23	0.12	0.76	0.15	0.64
Pg-M(aGo_l-aGo_r)	mandibular corpus lenght	0.08	0.07	0.11	0.01	0.03
aGo_l-aGo_r	lower facial width	1.08	0.93	1.38	0.10	0.45
N-Sn	Anterior upper facial	0.12	0.09	0.14	0.01	0.05
Ex_r-Ex_l	Upper facial width	0.95	0.16	1.39	0.32	1.22
Sn-Pg	Anterior lower facial height	0.17	0.14	0.21	0.02	0.07
T_r-T_l	Middle facial width	0.30	0.11	1.34	0.30	1.23
N-Prn	Nasion - Pronasale	0.12	0.09	0.14	0.01	0.05
Prn-Pg	Pronasale - Pogonion	0.17	0.14	0.21	0.02	0.07
Ls-(Prn-Pg)	Upper lip to E-line distance	0.17	0.14	0.21	0.02	0.07
Li- (Prn-Pg)	Lower lip to E-line distance	0.17	0.14	0.21	0.02	0.07
Mean Values		**0.30**	**0.07**	**1.39**	**0.11**	**1.32**

Table 4. Summary of the more significant measures for investigations conducted by other researchers

Measure	Description	Type	Prob.	α	t	sp	ng	Reference
N-Pg	facial line	Distance (mm)	100%	0.0	4.63	5.11	48	Ferrario Sforza 1995 Beauties (10) vs Normals (40) [19]
N-Sn	Anterior upper facial 2° third height	Distance (mm)	100%	0.0	9.22	3.04	48	
Sl-N-Sn	Maxillary prominence	Angle (deg.)	100%	0.0	5.02	1.62	48	
Ex_r-N-Ex_l	Upper Facial Convexity	Angle (deg.)	100%	0.0	4.69	6.81	48	
(N-Sn)/(N-Pg)		ratio	100%	0.0	9.61	0.01	48	
(Sn-Pg)/(N-Pg)		ratio	100%	0.0	9.61	0.01	48	
(Tr-N)/(Tr-Sn)		ratio	100%	0.0	5.19	0.03	48	
Ex_r-Ex_l	Upper facial width	Distance (mm)	100%	0.0	6.14	3.45	93	Sforza – Laino 2006 competition (24) vs ref (71) [24]
Ls-(Prn-Pg)	Upper lip to E-line distance	Distance (mm)	100%	0.0	4.47	1.33	93	
Li-(Prn-Pg)	Lower lip to E-line distance	Distance (mm)	100%	0.0	5.43	1.33	93	
(Sn-Ls)^(Sl-Pg)	Interlabial	Angle (deg.)	99.99%	0.0	4.03	7.78	93	
Ex_r-Ex_l	Upper facial width	Distance (mm)	100	0.0	5.68	3.73	93	Sforza – Laino Angle 2007 competition (24) vs ref (71) [24]
T_r-T_l	Middle facial width	Distance (mm)	99.4%	0.01	2.79	5.47	93	
Li-(Prn-Pg)	Lower lip to E-line distance	Distance (mm)	100%	0.0	4.47	1.61	93	

A third question is whether the measured samples of attractive women in the Miss Italia contest in 2010 (66 subjects) and attractive girls measured by the researchers mentioned belong or not, with statistical evidence, to the same population, or if the differences are such as to assume a population of "beautiful Miss Italy 2010" different from other populations of "beauties" reference subjects. The comparison between Peck & Peck (the first tests on measures skin landmark sample of attractive women) [20] and Miss Italy 2010 is particularly interesting: Peck & Peck analysed with a photographic method characteristic angles of the profile of 52 American actress in 1969: we can see that after 40 years and in another continent, the values are still very much in line. Only the mandibular angle and total vertical seems to be slightly higher for the subjects of Miss Italia.

Summarizing the results of the comparison of multiple samples, it is possible to obtain a very interesting indication of which are the facial parameters that diversify more different samples of attractive girls.
In particular are the most influential (table 5 and fig. 6):

- for the upper 3rd, the upper facial width *Ex_r-Ex_l*, the upper facial convexity angle *Ex_r-N-Ex_l*;
- For middle 3rd, average distance between the Nasion and the Midpoint of the Tragi *N-M(T_r-T_l)*, the angles nasolabial *Prn-Sn-Ls, T_l-N-T_r, T_l-Prn-T_r*;
- For the lower 3rd, the width of the mouth *Ch_r_Ch_l*; and the angles *T_l-Pg-T_r, (Sn-Ls)^(Sl-Pg)*.
- For the combined middle and lower 3rd, the maxillofacial angle *Mf (Pg-N-Ls)*.

Analyzing only the linear measurements, the major influences are those relating to:

- Width - upper facial width *Ex_r-Ex_l*, the width of the mouth *Ch_r-Ch_l*;
- Distance - the distance between the Nasion and the Midpoint of Tragi *N-M(T_r-T_l)*.

As for the angular measurements, the major influences are those related to:

- the upper facial convexity *Ex_r-N-Ex_l*, nasolabial angles *Prn-Sn-Ls, T_l-N-T_r, T_l-Prn-T_r, T_l-Pg-T_r, (Sn-Ls)^(Sl-Pg)*, the maxillofacial angle *Mf (Pg-N-Ls)*.

It is also important the relationship between sizes *(Sn-Pg/N-Sn) x100*.

5. Conclusions

The photogrammetric scanner confirms to be one of the best choice for facial anthropometry, being simple, fast, precise and cheap. The absence of ionizing radiation respect the directive 97/43/EURATOM, that says that radiographic exposure is justified only when the patient management depends on the information obtained the radiograph. The scanner allows to acquire huge samples for massive field analyzes. The relief of the sample recreate for all scanned subjects the same conditions in a reliable and fast way. Comparing the results, the tests show that the soft tissue landmark measurements were similar to those available in literature. This photogrammetric methodology can contribute to give to orthodontist and surgeon the reference standard measures, especially in terms of proportions related to women facial attractiveness.

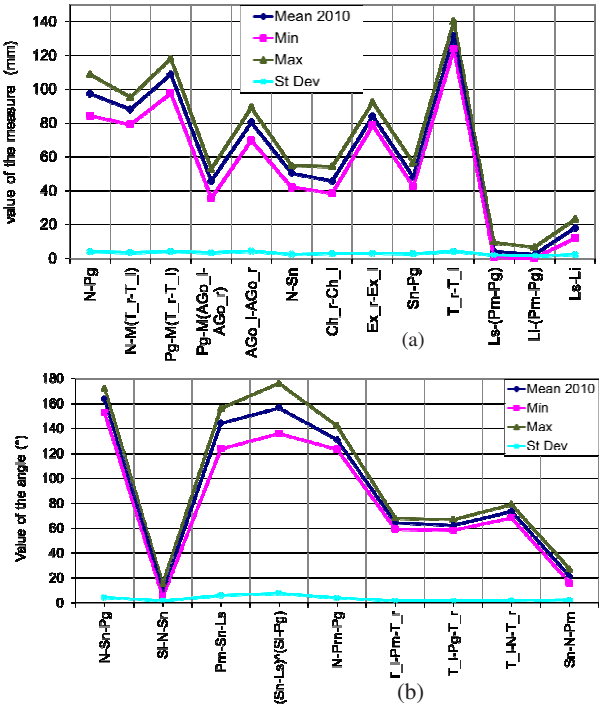

Fig. 5. Linear (a) and Angular (b) Measurements

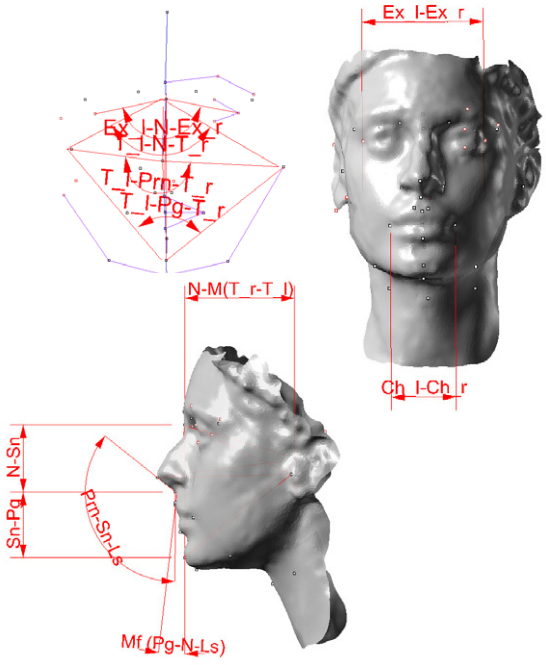

Fig. 6 - Most significant measures for attractiveness

Table 5. Most significant measures for attractiveness

Linear Measurements	Rank	Angular Measurements	Rank	Ratio
Ex_r-Ex_l	1	Prn-Sn-Ls	1	(Sn-Pg/N-Sn)
Ch_r-Ch_l	2	Ex_r-N-Ex_l	2	
N-M(T_r-T_l)	3	T_l-N-T_r	2	
		T_l-Pg-T_r	2	
		T_l-Prn-T_r	2	
		Mf (Pg-N-Ls)	2	

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