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3D Facial symmetry evaluation from high – density scanned data

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Abstract

Purpose:
This paper proposes a new method for the identification of the symmetry plane of the human face, starting from a 3D high – density scanned data. This plane is used to evaluate the local and mean asymmetries of the face.

Method:
The proposed method evaluates the symmetry plane taking into consideration the initial estimation of the symmetry plane performed by an iterative mirroring and registration-based method. Once the mirroring of the original data is carried out with respect to the symmetry plane which has been previously estimated, the source point cloud and the mirrored data are registered by the ICP algorithm that minimises a new weighted function. The final symmetry plane obtained approximates in the least-squares sense the midpoints of the lines connecting homologous points randomly chosen.

Result:
This method is validated by analysing some specifically-designed test cases. The obtained results show that the method is insensitive to local asymmetries, whether they be near or far from the symmetry plane, and is also repeatable and slightly conditioned by the acquisition process.

Discussion & Conclusion:
This method offers promising applications not just in the medical field but also in the face recognition field. Future work should address how to improve the performance of the method in terms of timing costs and how to use the symmetry plane for face feature segmentation and for facial authentication and recognition.

1 Introduction

For the last decade, and especially thanks to the development of 3D acquisition techniques, much of the research interest has turned towards the study of shape recognition and feature extraction from three-dimensional acquired objects. For their versatility, cheapness and non-invasiveness these techniques are also used in the biomedical field. A drawback in their use is the fact that the acquired data cannot be directly used, but needs processing so as to be able to recognise human body shapes and features. One of the most important human body features to be evaluated is bilateral symmetry. Since Antiquity studies concerning human face symmetry have tried to explain its attractiveness by means of sociological and psychological investigation. More recently, the issue of facial symmetry evaluation has been approached for several purposes such as:

- face authentication and recognition by middle profile feature extraction [1], [2],
- quantification of asymmetry in human face and development of computer-aided protocols for half-damaged face reconstruction or cosmetic surgery for aesthetic corrections in MFS (Maxillofacial Surgery) [3], [4],
- correlation between facial asymmetries and symmetry line for the back pathologies in Orthopaedics and Orthodontics [5],
- correlation between facial asymmetries and cognitive disorders for schizophrenia diagnosis in Neurology [6].

It is on account of the importance of this issue that numerous algorithms for human face symmetry plane detection and asymmetry quantification are presented in literature. These evaluations are blurred by the fact that perfect symmetry is an ideal condition, never to be verified in the case of real human faces. Face asymmetry can occur in non-bilateral symmetry of single features such as ear displacement or asymmetry which affects face shape as a whole. Such is the case, for instance, of a face in which the symmetry line is not located on a symmetry plane. Furthermore, in the case of acquired faces, facial asymmetries can result from the acquisition process and not from the geometric shape. We are talking about asymmetrical or non-uniform sampling of the face. Many of the methods presented in the related literature do not distinguish asymmetries of the shape from those coming from the acquisition process. They focus on the point cloud and not on the shape represented by it.

In order to evaluate the symmetry plane of face features starting from 3D high–density scanned facial data, this paper puts forth a new method. This plane is used to evaluate the local and mean asymmetries of the face. The robustness, accuracy and sensitivity of the method are checked by processing some test cases.

2 Related works

The methods for human face symmetry plane detection can be classified based on:

- Extended Gaussian Image (*EGI*),
- mirroring and registration,
- direct estimation.

The methods belonging to the first category [7] and [8], analyse the recurrence histogram of the orientation of the normal unit vectors of the tessellated surface under the hypothesis that such a histogram (discrete version of *EGI*) presents the same symmetry as the object. In [9] the authors search for the maximum degree of symmetry only around the principal axes of inertia of the orientation histogram for a generic object, including a human face. As pointed out by Pan et al. in [8], for 3D noisy facial data, the directions of these principal axes are affected by large errors. Thus, in order to work out this problem, the authors put forth a method which extends the search space, but which also increases computational costs.

The mirroring and registration-based methods exploit the bilateral features of the human face for facial symmetry plane detection. In general, they are structured in the following steps:

- the initial estimation of the symmetry plane Π_0,
- the mirroring of the original data (*PC*), from *PC* into $Mod = Mir(PC) = PC_m$, with respect to Π_0,
- the *Iterative Closest Point* algorithm-based (*ICP* [10]) registration between mirrored (PC_m) and original data (*PC*),
- the final estimation of the symmetry plane Π_f.

M. Benz et al. [3] were the first to propose the mirroring and registration-based method in order to support aesthetic surgical facial reconstruction. Their work aims at the detection of the symmetry plane by means of which the healthy half can be mirrored onto the damaged half for its reconstruction. The authors highlight how the choice of typically healthy areas in a damaged face (nose, chin and forehead) turns out to be sufficient to register the original data and the mirrored data through a specific *ICP* algorithm [11]. The final symmetry plane obtained approximates in the least-squares sense the middle points of the lines connecting homologous points randomly chosen.

Another non–automatic approach is proposed by De Momi et al. in [4]. The authors use a typical *ICP* algorithm-based method so as to perform, in a specific way, the first-attempt estimation of the symmetry plane. This plane is obtained by evaluating the symmetrical location of two homologous patches which have been manually selected. It is the symmetry plane of the centroids of selected areas. In order to develop a fully automatic method, Colbry and Stockman in [12] put forward an approach whereby the first-attempt symmetry plane is evaluated by the *Principal Component Analysis* (*PCA*) method [13]. Tang *et al.* pointed out in [14] that the *PCA* method could in some cases perform so inaccurate an initial estimation of the symmetry plane that the subsequent *ICP* registration algorithm could not converge. In order to overcome this limitation, in [14] the authors propose the plane being parallel to the yz – plane and passing through the centroid of the face for an initial estimate. This approach works correctly only if the real symmetry plane is aligned with the yz – plane of the scanning device. If a method which is both fast and insensitive to asymmetrical data of the face is to be developed, the registration should only concern a rectangular region around the nose because of its stiffness. It is a valid approach only in the case of undistorted noses.

ICP algorithms are the main cause for a rise in computational costs so great efforts have been directed towards speeding up this algorithm [1], [15]. Zhang *et al.* in [2] highlight that the *ICP* algorithm could fail when there are irregularities in the face boundary. Therefore, in their paper, the authors propose the *MarkSkirt* operator which excludes from the registration the points belonging to the 10–ring of the boundary.

More recently, Combès *et al.* in [16], [17] and [18] present an approach that directly estimates the symmetry plane without intermediate roto–translation transformation and registration. Once the initial estimation of the symmetry plane is performed by the *PCA* method, its final evaluation Π_f is done by an iterative algorithm that converges to a (at least local) minimum of a properly designed function. In particular, this function is the sum of the weighted distances between the points reflected with respect to Π_f and the corresponding nearest points of the cloud. With a view to leaving out the asymmetric sampled area of the model, weights are expressed as the *Leclerc function* [19]. Furthermore, some implementation solutions are proposed in order to make the method fast and robust. The problem of the non-symmetrical sampling of the face is solved by this method but it is still very sensitive to non-uniformity in the sampling. Two homologous surfaces which are perfectly symmetric but which are characterised by different sampling density may turn out to be asymmetric due to the distance between the source point cloud and the mirrored – registered one.

3 The proposed method

In general, any geometric form *S* in three dimensions is said to be bilaterally symmetric with respect to Π if its mirror image (S_Π) upon Π is partially or completely superimposable onto the original form. The plane Π is the *symmetry plane* of *S*. Perfect symmetry is an ideal condition that is not verified in any real object, let alone in the case of human faces. Furthermore, no method for the symmetry plane estimation of a geometric facial feature can verify the previous symmetry definition. Therefore for any symmetrical object, the measure of non–ideal symmetry requires to be evaluated; symmetry is conventionally recognised to exist whenever this measure is lower than a threshold value.

If an object is defined by a point cloud, the symmetry property refers to the shape it has and not to the point cloud itself. In that way, the asymmetries due to the surface density sampling, which affects the methods for symmetry plane estimation presented in literature, are reduced. Asymmetry can also be due to the asymmetry of the acquired area of the face. These asymmetries are mainly due to hairline and to irregularities in the borders of the acquired surface.

Finally, the evaluation of the symmetry plane of a human face can be affected by isolated local particularities, such as local damage, pimples, bumps, etc. and asymmetric facial expressions. Although these local particularities do not modify the general symmetrical nature of the face, they could affect the automatic estimation of the symmetry plane.

The proposed method is therefore designed to overcome the above-mentioned limitations. It consists of the following steps:

1) 3D acquisition of the subject's face *PC*,
2) first-attempt estimation of the symmetry plane Π_0,
3) mirroring and registration,

4) final estimation of the symmetry plane Π_f;
5) asymmetry evaluation: a_l (local asymmetry), a_m(mean asymmetry).

3.1 Face acquisition

The facial surface to be analysed is acquired by means of a 3D geometric scanner [20]. In order to reduce outliers and large noise, the scanned point cloud is first smoothed by a Gaussian filter and then tessellated.

3.2 First-attempt estimation of the symmetry plane

The first-attempt estimation of the symmetry plane is obtained by means of a symmetry line detection method which is typically used in spinal spatial configuration representation [21]. That method is not sensitive to the asymmetries of the acquired area of the face but, in order to be applied, it requires a rough evaluation of the facial *longitudinal axis*. Thus, to begin with, the *longitudinal* axis is roughly detected by a *PCA* applied to the set of points in the front side of the plane which best fits the point cloud of the acquired face (figure 1). The direction of the *longitudinal axis* $\boldsymbol{\zeta_G}$ is calculated as the principal axis of inertia, associated with a lower inertia moment, of the set of selected points.

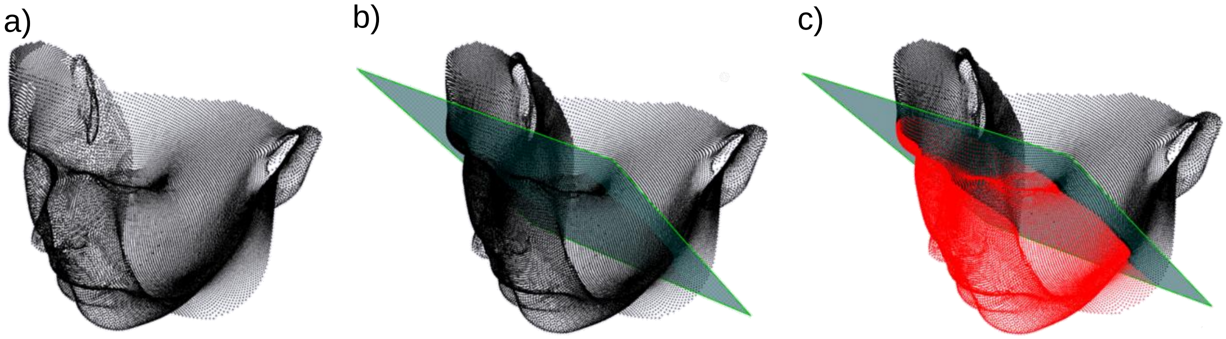


Fig. 1 3D source data (a), source data and its best fitting plane (b), red highlighted ROI: set of points, in the front side of the plane which best fits the point cloud, here used to detect the longitudinal axis (c).

As evidenced by [14], a good initial estimation of the symmetry plane greatly influences the subsequent registration by the *ICP* algorithm. The evaluation of the first-attempt symmetry plane is performed by analysing the slice profiles obtained when sectioning the tessellated face with a set of planes which are perpendicular to the previously-estimated *longitudinal axis*. For each slice profile, the most symmetric point is characterised by the maximal value of a properly defined *symmetry index* [21]. The *symmetry index* which is here being used is based on the analysis of the symmetry in the orientation of the normal unit vectors of the slice profile. The symmetry line thus detected almost lies on the symmetry plane. The symmetry plane of the first attempt (Π_0) is obtained by approximating the above-defined symmetric points in the least-squares sense**.**

3.3 Final estimation of the symmetry plane

Once the initial estimation of the symmetry plane (Π_0) is obtained, the refinement algorithm is applied. The method consists in an iterative estimation of the symmetry plane by mirroring ($PC_{m,i}$) the original data PC with respect to Π_i:

$$PC_{m,i}=\{\boldsymbol{q}_{i,j},\ j=1,\ldots n\} : \boldsymbol{q}_{i,j}= S_{\Pi i}(\boldsymbol{p}_j),\ \forall\, \boldsymbol{p}_j \in PC$$

Then the source point cloud (PC) and the mirrored data ($PC_{m,i}$) are registered by the *ICP* algorithm minimising the following function:

$$\frac{\sum_{j=1}^{n} w_{i,j}\cdot Haus\left(\boldsymbol{p}_j, TS\left(PC_{m,i}\right)\right)}{\sum_{j=1}^{n} w_{i,j}} \qquad (1)$$

where:

n is the number of points of PC;

$\boldsymbol{p}_j$ is the $j-th$ point belonging to PC;

$TS(PC_{m,i})$ is the tessellated surface relative to point cloud $PC_{m,i}$;

$Haus(\boldsymbol{p}_j)$ is the *Hausdorff distance* between $\boldsymbol{p}_j$ and the tessellated surface $TS(PC_{m,i})$ according to the following equation:

$$Haus\left(\boldsymbol{p}_j,\ TS\left(PC_{m,i}\right)\right)=\min_{q_{i,j}\in TS\left(PC_{m,i}\right)}\left\|\boldsymbol{q}_{i,j}-\boldsymbol{p}_j\right\|_2 \qquad (2)$$

$w_{i,j}$ is the weight expressed as the product of two specific weights:

$$w_{i,j}=w_{s,i,j}\cdot w_{r,i,j} \qquad (3)$$

The first weight $w_{s,i,j}$ makes it possible to exclude any asymmetries from the registration process on the assumption that the nearest points to the symmetry plane must have higher weight than the remaining. $w_{s,i,j}$ is expressed according to the *Leclerc function*:

$$w_{s,i,j}=\frac{1}{\sigma_s^2}\cdot e^{-\left(\frac{d_{i,j}}{\sigma_s}\right)^2} \qquad (4)$$

$d_{i,j}$ is the distance between $\mathbf{p}_j$ and the symmetry plane Π_i.

The second weight $w_{r,i,j}$ works as a filter which excludes from the registration process any local asymmetries, whether they be near or far from the symmetry plane. It is defined according to the *Leclerc function*:

$$w_{r,i,j}=\frac{1}{\sigma_r^2}\cdot e^{-\left(\frac{r_{i,j}}{\sigma_r}\right)^2} \qquad (5)$$

where:

$r_{i,j}$ is the distance between $\boldsymbol{p}_j \in PC$ and $\tilde{\boldsymbol{q}}_{i,j}$ which is the nearest point to $\boldsymbol{p}_j$ belonging to the tessellated surface $TS(PC_{m,i})$ and satisfying equation (2).

σ_r and σ_s values affect the registration results. All in all, large values of σ_r and σ_s afford great robustness whereas a small value affords great accuracy. In order to balance both necessities, in the following experiment the value of σ_s is assumed to be the 25 per cent of the maximal width of the face and σ_r is fixed as $\frac{\sigma_s}{10}$.

After surface registration is complete, the symmetry plane Π_{i+1} is evaluated by randomly choosing 10 000 points of *PC* and the corresponding ones from the mirrored-registered point cloud ($PC_{m,i,r}$). For each pair of corresponding points ($\boldsymbol{p}_j$, $\boldsymbol{q}_{i,j}$) the middle point $\mathbf{m}_{i,j} = \frac{\mathbf{p}_j + \mathbf{q}_{i,j}}{2}$ is calculated. Finally, Π_{i+1} is obtained as the plane that approximates all the $\mathbf{m}_{i,j}$ points in the least-squares sense.

The iterative process comes to an end when the variation of function (1) between two iteration cycles is lower than the imposed threshold value of 0.01 or when the number of iterations is equal to 100.

3.4 Asymmetry evaluation

In the method herein proposed, once the symmetry plane has been evaluated, the local and mean asymmetries of the human face are quantified. In particular, the *local asymmetry* (a_l) and the *mean asymmetry* (a_m) are defined by the following expressions:

$$a_l(p_j) = \left\| \hat{\boldsymbol{q}}_j - \boldsymbol{p}_j \right\| \quad \forall\, \boldsymbol{p}_j \in PC \qquad (6)$$

$$a_m(PC) = \frac{\sum_{j=1}^{n} a_l(p_j)}{n} \qquad (7)$$

where $\hat{\boldsymbol{q}}_j$ is the nearest point to $\boldsymbol{p}_j$ belonging to PC_{mr} and *n* is the number of points of *PC*.

4 Experimental results

The proposed method has been implemented in original software, coded in C++, called INGEMANTICA, which is suited to process and analyse tessellated geometric models.

A first experiment is carried out in order to verify how the local asymmetries affect the estimation of the symmetry plane. This is done by comparing the symmetry plane of a nominally bilaterally symmetric face (figure 2a [22]) with that of the face resulting from adding to the former an asymmetric deformation (figure 2b) and an asymmetric sampling (figure 2c). Table 1 reports the results, expressed as the angle (α [°]) and the distance between the obtained plane and the nominal one. Figure 3 reports the corresponding maps of the local asymmetries for the meshes of figures 2b and 2c. The maps evidence a quite perfect localisation of the local asymmetries verifying the correct estimation of the whole symmetry plane (figure 3).

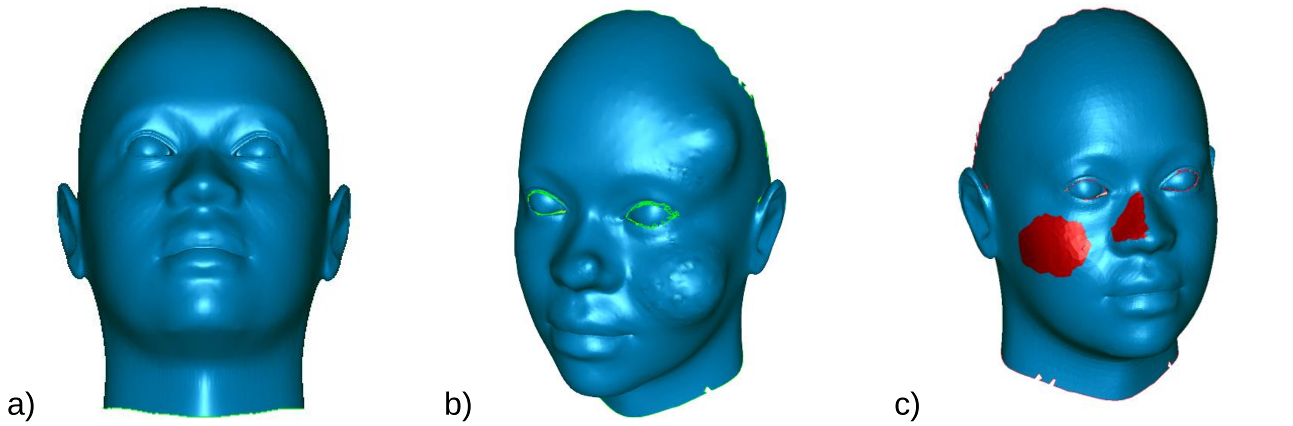


***Fig. 2** Data with nominally bilaterally symmetry (a), with added asymmetric deformations (b) and asymmetric sampling (c).*

Test case	α [°]	dist [mm]
face with nominally bilaterally symmetry and added asymmetric deformations	0.12	0.08
face with nominally bilaterally symmetry and added asymmetric sampling	0.09	0.04

***Tab. 1** Results regarding robustness against local asymmetries.*

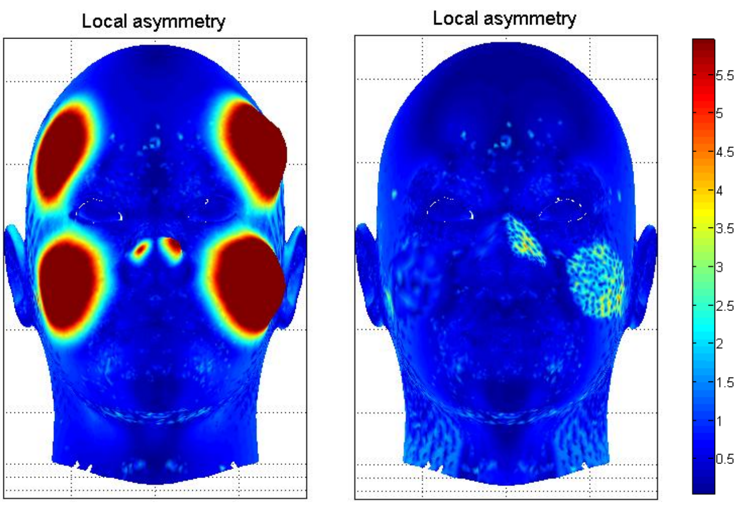


***Fig. 3** The maps of the local asymmetries for the faces in figure 2.*

The second set of experiments is performed in order to verify the reproducibility in the determination of both the symmetry plane and the *mean asymmetry*. This is investigated by analysing 11 different acquisitions of the face of a male test person with no visible facial asymmetries maintaining the same neutral facial expression and closed eyes. Figure 4 depicts one of the acquired faces.

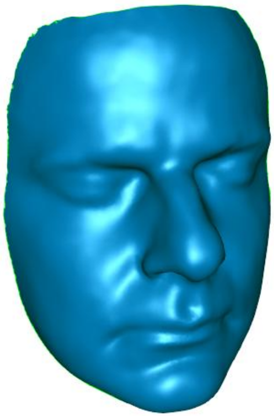


Fig. 4 One of the acquired faces of the subject used to verify the reproducibility of the method.

Since the different acquisitions are carried out without fixing a relative position of the subject in the scanning device, the reproducibility of the symmetry plane is evaluated in the following indirect way:

- Out of 11 scannings, one is randomly chosen as a reference face,
- the remaining 10 faces are each registered at the reference one by using function (1),
- the corresponding symmetry plane of the registered face is estimated by the method here being proposed and any difference from the reference face is measured as the angle between the related normal unit vectors.

So, for the *i – th* face the angle φ_i is defined as:

$$\varphi_i = \arccos\left(\mathbf{n}_r \cdot \mathbf{n}_{i,reg}\right) \quad (8)$$

where:

$\mathbf{n}_r$ is the normal unit vector of the symmetry plane of the reference face;

$\mathbf{n}_{i,reg}$ is the normal unit vector of the symmetry plane of the *i – th* face, expressed in the coordinate system of the reference face.

In table 2 the results for reproducibility are reported in terms of mean and standard deviation values of φ_i and a_m. The obtained values demonstrate that, in practical situations, the method is little affected by the acquisition process. These results are comparable with those obtained through experimentation in [23] as concerns daily singular acquisitions for several days while maintaining the three-dimensional device setting fixed with respect to the acquired subject.

parameter	Mean value	Std value
φ_i [°]	0.58	0.39
a_m [mm]	1.54	0.14

Tab. 2 Results for reproducibility.

The third set of experiments seeks to verify the sensitivity of the method by analysing the face of the same subject assuming different facial expressions. This is done by analysing the scanned face data available on the Bosphorus database [24]. In particular, this experimentation consists in the analysis of five nominally-symmetric facial expressions and the two most asymmetric ones out of three randomly chosen subjects. For each subject, the five symmetric facial expressions are used to define the following *reference normal unit vector* of the estimated symmetry plane:

$$\mathbf{n}_r = \frac{\sum_{i=1}^{5} \mathbf{n}_i}{5} \quad (9)$$

Hence, for each of the two asymmetric facial expressions of the same subject, φ_i is defined as follows:

$$\varphi_i = \arccos\left(\mathbf{n}_r \cdot \mathbf{n}_i\right) \quad (10)$$

where $\mathbf{n}_r$ is the *normal unit vector* defined in (9) and $\mathbf{n}_i$ is the corresponding normal unit vector of the symmetry plane. Table 3 shows the results in terms of φ_i, a_m (defined in according with (7)) and map of a_l (defined in according with (6)). In the same table, the subject and the facial expression labels are those taken from the Bosphorus database. The φ_i values obtained attest to how the method being put forth for symmetry plane detection shows a satisfactory insensitivity even to those asymmetries due to facial expressions.

5 Conclusion

This paper presents a new method for the whole symmetry plane detection of the human face from 3D high–density scanned data. Starting from the first attempt symmetry plane, the proposed approach converges to the best evaluation by an iterative mirroring and registration-based method.

Furthermore, the method is validated by analysing some specifically-designed test cases. In particular, ideal bilaterally-symmetric faces with known, added local asymmetries are used to verify how the latter affect the estimation of the symmetry plane. The reproducibility in the determination of the symmetry plane and the *mean asymmetry* is investigated by analysing 10 different acquisitions, done through several days, of the face of a male test person with no visible facial asymmetries and maintaining the same neutral facial expression and closed eyes. Finally, the sensitivity of the method is tested by studying the face of the same subject assuming different facial expressions.

The results obtained show that the proposed method can be practically insensitive to local asymmetries, whenever they are localised on the face (far from or near the symmetry plane), are reproducible and are not affected by the acquisition process (non-uniformity of point cloud density, non-symmetric acquired area).

Future work should address to the improvement of method performances in terms of computational costs. Furthermore, efforts will be directed toward verifying if the method here proposed is successfully applicable for typical facial features segmentation (e.g. nose, eyes, mouth, chin, ears) and in face authentication and recognition.

References

[1] G. Pan and Z. Wu. *3d face recognition from range data*. International Journal of Image and Graphics, 5(3):1.21, 2005.

[2] L. Zhang, A. Razdan, G. Farin, M. S. Bae, J. Femiani. *3d face authentication and recognition based in bilateral symmetry analysis*. Journal of Visual Computer, 22(1):43.55, 2006.

[3] M. Benz, X. Laboureux, T. Maier, et al. *The Symmetry of Faces*. Proceedings of VMV'2002. Erlangen, Germany.

[4] E. De Momi, J. Chapuis, I. Pappas, G. Ferrigno, W. Hallermann, A. Schramm, M. Caversaccio. *Automatic extraction of the mid-facial plane for craniomaxillofacial surgery planning*. Int. J. Oral Maxillofac. Surg. 2006; 35: 636–642.

[5] H. Ikemitsu, R. Zeze, K. Yuasa, K. Izumi. *The relationship between jaw deformity and scoliosis*. Oral Radiol (2006) 22:14–17.

[6] R.J. Hennessy et al. Facial shape and asymmetry by threedimensional laser surface scanning covary with cognition in a sexually dimorphic manner. J Neuropsychiatry Clin Neurosci, vol. 18, no. 1, pp. 73–80, 2006.

[7] B. K. P. Horn, *Extended Gaussian Image*. Massachusetts Institute of Technology Artificial Intelligence Laboratory, A.I. Memo No. 740, 1983.

[8] G. Pan, Y. Wang, Y. Qi, Z. Wu. *Finding Symmetry Plane of 3D Face Shape*. International Conference on Pattern Recognition [1051-4651] Pan yr: 2006 vol:3 pg:1143.

[9] C. Sun, J. Sherrah. *3D Symmetry Detection Using The Extended Gaussian Image*. IEEE transactions on pattern analysis and machine intelligence [0162-8828] Sun yr: 1997 vol: 19 iss: 2 pg:164.

[10] P. J. Besl, N. D. McKay. *A method for registration of 3D shapes*. IEEE Trans. Pattern Anal. Mach. Intell., 14(2):239. 256, 1992.

[11] S. Seeger, X. Laboureux, G. Häusler. *An Accelerated ICP - Algorithm*. Lehrstuhl für Optik, Annual Report, Erlangen, (2001).

[12] D. Colbry, G. Stockman. *Canonical face depth map: A robust 3d representation for face verification*. In CVPR '07: Proceedings of the 2007 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'07), pages 1.7, Minneapolis, MN, USA, 2007.

[13] K. Pearson. On Lines and Planes of Closest Fit to Systems of Points in Space. Philosophical Magazine 2 (6): 559–572. 1901.

[14] X. M. Tang, J. S. Chen, Y. S. Moon. *Accurate 3d face registration based on the symmetry plane analysis on nose regions*. 16th European Signal Processing Conference (EUSIPCO 2008), Lausanne, Switzerland, August 25-29, 2008

[15] S. Rusinkiewicz, O. Hall-Holt, M. Levoy. *Real-time 3D model acquisition*. Computer Graphics Proceedings SIGGRAPH 2002, pp. 438–446.

[16] B. Combès, R. Hennessy, J. Waddington, N. Roberts, S. Prima. *Automatic symmetry plane estimation of bilateral objects in point clouds*. International conference on computer vision and pattern recognition 2008, Anchorage: United States, 2008.

[17] B. Combès, R. Hennessy, J. Waddington, N. Roberts, S. Prima. *AN ALGORITHM TO MAP ASYMMETRIES OF BILATERAL OBJECTS IN POINT CLOUDS*. International Symposium on Biomedical Imaging: From Nano to Macro, Paris: France, 2008.

[18] B. Combès, S. Prima. *New algorithms to map asymmetries of 3D surfaces*. International Conference on Medical Image Computing and Computer Assisted Intervention, 2008.

[19] MJ Black, A. Rangarajan. *On the unification of line processes, outlier rejection, and robust statistics*. Intern J Comput Vis. 1996;19:57–91.

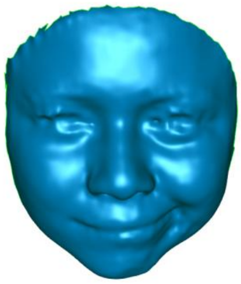
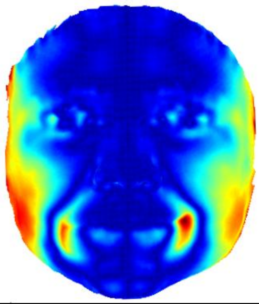
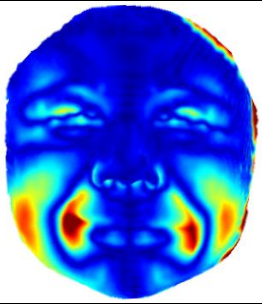
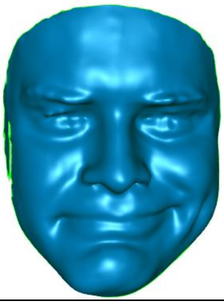
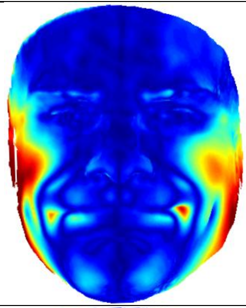
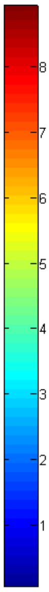
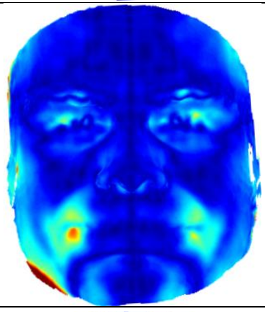
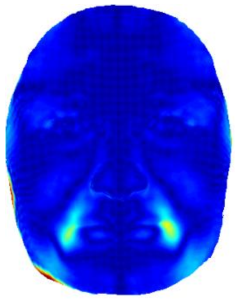
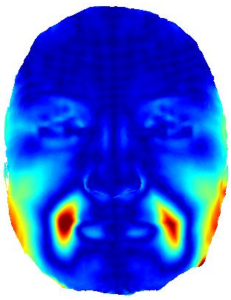
[20] Scansystem website. http://www.scansystems.it. Accessed 2010.

[21] Di Angelo L, Di Stefano P, Vinciguerra MG. *Experimental validation of a new method for symmetry line detection*. Computer – Aided Design and Applications 2011; vol. 8 (1):71-86.

[22] Singular Inversions website. http://www.facegen.com/downloads.htm. Accessed 2010.

[23] J. Hartmann, Ph. Meyer-Marcotty, M. Benz et al.. Reliability of a method for computing facial symmetry plane and degree of asymmetry based on 3D data. J Orofacial Orthopedics 2007; 68: 477–90.

[24] A. Savran, N. Alyüz, H. Dibeklioğlu, O. Çeliktutan, B. Gökberk, B. Sankur, L. Akarun. *Bosphorus Database for 3D Face Analysis*. The First COST 2101 Workshop on Biometrics and Identity Management (BIOID 2008), Roskilde University, Denmark, 7-9 May 2008.

Subject label	Expression label	STL model	φ_i [°]	a_m [mm]	map of a_l	
086	pull_up_lip_left_corner		2.25	1.93		
	pull_up_lip_right_corner		5.95	1.67		
098	pull_up_lip_left_corner		2.03	1.77		
	pull_up_lip_right_corner		2.05	1.46		
103	pull_up_lip_left_corner		2.46	1.45		
	pull_up_lip_right_corner		3.11	0.83		

Tab. 3 Results regarding sensitivity.