3D Facial Biometric Database – Search and Reconstruction of Objects Based on PCA Modes

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Abstract. This article presents application of modal analysis for the computation of biometric data base (3D faces) and extraction of three dimensional geometrical features. Traditional anthropometric database contains information only about some characteristic points recorded as linear or angular dimensions. The current face recognition systems are also based on the two-dimensional information. To increase level of security the methods need to operate on three-dimensional data. In the article authors present of 3D modal analysis, for decomposition, extraction features and individual coding of analyzed objects sets. Authors apply empirical modal analysis PCA (Principal Component Analysis) for 3D data of human faces. Additionally for face recognition, the comparison of reconstruction with different number of modes are presented and discussed.

Keywords: 3D geometry reconstruction, data registration, low-dimensional model, modal analysis, Principal Component Analysis (PCA).

1 Introduction

Human face is the one of the elements of our being, which is using for recognition of the people. This is the most natural and one of the oldest (next to voice recognition) known biometric systems that are in daily use for thousands of years.

From the first days of life man develops the ability to memorize and recognize facial features. Skill of the face recognition with voice recognition ability gives us the possibility almost 100% effective in identifying persons. However, this high efficiency is reserved only for the people we know. In case that we do not know the person (thereby her facial features and voice), we are not able to capture the subtle differences but only the general features and significant differences.

Biometrics identifies people by measuring some individual aspects of anatomy, physiology or other behavioral characteristic [1]. Nowadays can biometric systems can used many different elements e.g.: face, fingerprints, hand geometry, signature or voice. Type features used to identify persons determines use of the different input data, such as the shape of the face [3, 17], hand [8, 18] and even the whole human body [2].

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Facial identification reads the peaks and valleys of facial features, known as nodal points. In a human face there exist 80 points, but usually only 15-20 of them, known as „Golden triangle", are used for identification.

The problem with face recognition is not only acquisition of the clear data, but also many other aspects like illumination, clothing parts (hat, sunglasses, jewelry), hairiness (beard, long hair), makeup. Some of these elements can be used in everyday life to face beautify, but also somebody can specifically used to falsify the true facial features [5]. Another aspect of face geometry except facial expression is lip movements and facial muscles during speaking.

Insufficient reliability of the currently used 2D recognition techniques (photos contain less information then the 3D surface) stimulates interest in 3D or even 4D techniques [11].

In future research works, more aspects of using 3D/4D biometrical systems should be considered include also the ergonomics. Ergonomic quality, is not as earlier dependent on one or several factors that a user can affect, but results from a whole range of elements of the macro environment [4].

Rapid increase of the amount of data to be analyzed leads to the need for modal analysis methods. These methods are used to simplify and minimize the number of parameters which describe objects. The kind of used modal method: mathematical, physical or empirical (PCA/POD), has a fundamental influence on the results [12, 13].

This paper will present advances in use of 3D face biometric database based on Principal Component Analysis. In further sections will be presents and discuss procedure of collecting 3D data, PCA decomposition and 3D face geometry reconstruction of the real data.

2 Acquisition of 3D Face – Input Data

There are several methods which can be used to collect data of the 3D face geometry. In 2D biometric systems usually the single camera is used. In this approach, the most important is adequate lighting of the face and ensure visibility of the most important points in the area of the so-called. "golden triangle".

It is possible to create the 3D object from single two-dimensional image [9], but obtained model is not always high accuracy. From this reason it can be not enough for more complex 3D systems. For better results the stereo acquisitions systems or 3D scanners can be used. Stereo acquisition systems based on images, collected in the same time from two or more cameras [15]. Depending on used algorithms the different results are obtained. The newest systems are fast enough to acquire and processing 3D data in real time, creating 4D systems in which the fourth dimension is time [11]. The more accurate 3D models (higher resolution data) offer 3D scanners. Usually for biometrics the touch less (optical) methods are used. There are two most often techniques used: structural light scanners and laser scanners. Disadvantage of such solution is necessary to use, in addition to camera, an extra medium (as a structured light pattern or laser beam) and longer time off data acquisition (laser scanners). Furthermore the laser scanners are slower than stereo acquisition systems and structural light scanners.

In presented work the professional 3D structural light scanner was used. For this scanner the measuring volume is 400x300x210mm with resolution 0.05mm.

In order to provide equal conditions of scanning for all objects (human faces) during measuring process, the special face positioner was used (Fig. 1. a). The purpose of positioner is providing a similar setting for each scanned face: optimal measuring distance (about 90cm from the scanner detector), increase stability (elimination of involuntary head movement during data recording) and repeatability position regardless of the individual features of the scanned person. The positioner has a special pitch angle with lock, allowing head set in the range of angles of +/– 75^0 (Fig. 1. b).

a) b)

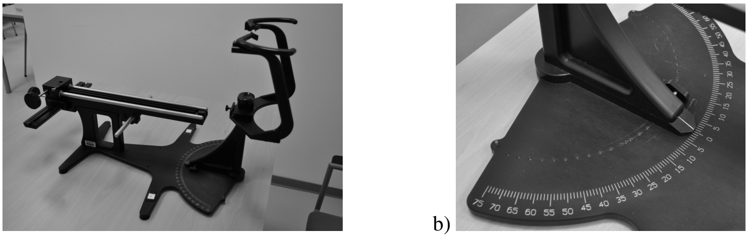

Fig. 1. The special face positioner: a) general view, b) pitch angle with the locking position

Each person subjected the scan takes place on a chair and puts his face to the abutment elements of the positioner. The face of a person is measured from three different directions in the three consecutive measurements (Figure 2 a, b, c). The first measurement is set "an face" corresponding to an angle of 0^0 to the positioner, the second measurement refers to the right facial profile and is made with 45^0 set on the positioner, third measurement shows left profile face (-30^0 angle positioner). The asymmetry of the angular set positioner result of the construction of a scanner having only one detector. Each measurement is performed with a facial expression similar to recommended in the performance of two-dimensional images of biometric documents.

a) b) c)

Fig. 2. The face scanning procedure: a) right profile of the face (positioner angle $+45^0$, b) an face direction, c) left profile of the face (positioner angle -30^0).

The result of the scanning process is a set of three point clouds (Fig. 3. a) containing a total of about 750k measuring points describing the geometry of the face from three different directions.

Each obtained point cloud were subjected to processing of: removing the errors of points (called noise), smoothing and removing the discontinuity areas that contain other components such as ears, fragments of the neck, the hairs (Fig. 3 b).

The next steps have been to overlapping (the registration process) and connect the individual point clouds into one homogenous (Fig. 3 c).

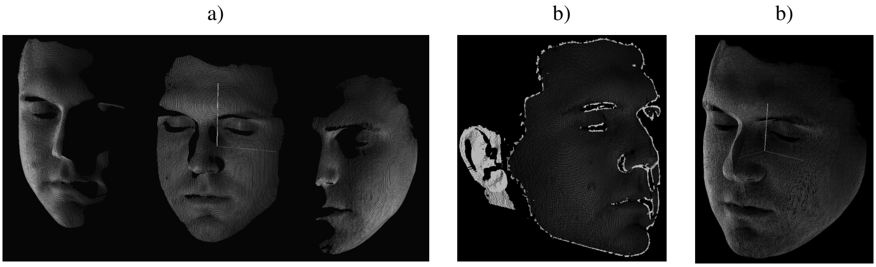

Fig. 3. The point clouds processing: a) set of scanned data from three directions, b) removing of the errors (bright color), c) final homogenous point cloud of the face

In the last stage the point cloud were subjected to triangulation process – "coupling" triangle mesh at each points of the cloud. The resulting surface model still requires further treatment related with the removal of triangulation errors and fill gaps in the data source. The final result of processing is three-dimensional surface mesh consisting of about 500k triangles, describing the face of the person being scanned.

In this work more than 100 faces of different persons (male and female, age: 22-24 years old) with neutral expression was acquired.

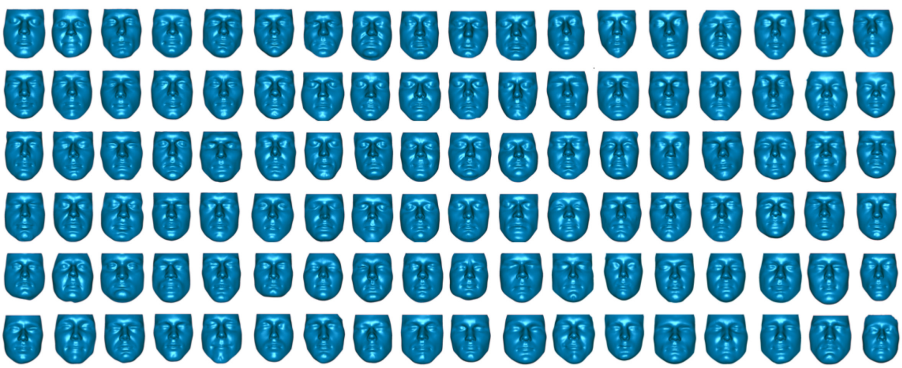

Fig. 4. Visualization of the 3D face database – more than 100 faces of different persons.

3 3D Data Registration

To enable fast work with the large number of data – 3D face database – the modal decomposition can be used. There are several types of modal methods but one of the well known are methods based Proper Orthogonal Decomposition (POD) or Principal Component Analysis (PCA). These methods have some variants like: Snapshot method, Kernel PCA [6], Multilinear PCA [10] or Generalized POD.

PCA provides a “relevant” set of basis functions, which allows construction of a low-dimensional subspace. PCA modes are optimal from viewpoint of information included inside of the each modes. The shape of each object is represented in the data base as the set of 3D polygonal surface and stored as a vector. PCA consists in centering of objects (by subtracting the average geometry) and the calculation of the covariance matrix [7]. Eigenvectors of this matrix (PCA modes) represent the geometrical features (shape) of the object

The Principal Component Analysis requires the same position, orientation and topology of the data input (the same number of nodes, matrix connection, etc.) for all objects. To achieve this, each new object added to database must be registered.

The registration process used in this work is performed by special developed algorithm and numerical tool (based on kd-tree searching algorithm) which is consists of three stages [14].

First stage (preliminary registration) – involves series of affine transformations (shift, rotation and scaling) to set scanned face on position in a coordinate system.

The second stage (elastic registration) consists of five steps:

1. Detection of edge elements lying on the boundary of the face;
2. Automatic detection of 16 specific points on the surface of the registrant face defining regional features: eyes, nose, mouth, beard / chin;
3. The displacement of boundary curve points of reference grid onto new position on registrant grid;
4. Displacement of characteristic points of the reference grid in the corresponding position on the registrant grid;
5. Interpolation of the position of other nodes on reference grid basing on the known boundary conditions.

The third stage (finishing registration) – is the transfer of all the nodes in the reference grid to the position defined by the points lying on the registered grid.

The result of the applied registration procedure is description of all faces in data base by the same (in topological meaning) surface mesh. The value of standard deviation between source and registered faces was 0.054mm and average distance 0.008mm.

4 Modal Decomposition of 3D Faces Database

PCA decomposition gives orthogonal directions of principal variation of input data. Variation is described by eigenvalue related to the first principal component. The further principal components, describe the next in order, orthogonal directions in the space with the largest variation of data.

Generally only few first principal components are describing majority variations of the data. Data projected onto other principal components often has small amplitude, lower than value of measurement noise (scanner error). Therefore they can be deleted, without decreasing the accuracy. The used algorithm is based on statistical representation of the random variables [16].

Because few first modes carry most information, therefore each original object S_i is reconstructed by using some K principal components (1):

$$S_i = \overline{S} + \sum_{k=1}^{K} a_{ki}\Psi_k \ , \ i = 1,2,\ldots,M, \tag{1}$$

where Ψ_k is an eigenvector representing the orthogonal mode (the feature computed from data base), a_{ki} is coefficient of eigenvector.

For prepared database of human faces the PCA analysis was performed. The result of this operation is the mean face, modes and a set of coefficients values (Fig. 5). To reconstruct 90% of information about decomposed geometry, it is enough to used the first 19 modes (Table 1).

Table 1. Participation of the first 20 modes in PCA decomposition of 3D faces

Number of the mode	Participation of the mode [%]	Total participation of the modes [%]
1	24,6826618	24,6826618
2	13,8607809	38,5434427
3	9,2869719	47,8304146
4	8,0263284	55,8567429
5	6,6289872	62,4857302
6	5,4689992	67,9547294
7	4,2335093	72,1882386
8	3,4046341	75,5928727
9	3,0812213	78,6740939
10	2,0491344	80,7232284
11	1,9885962	82,7118246
12	1,4060026	84,1178272
13	1,2429369	85,3607641
14	1,0910051	86,4517692
15	0,9615076	87,4132768
16	0,8416507	88,2549274
17	0,7555748	89,0105023
18	0,7096819	89,7201841
19	0,6701088	90,3902929
20	0,6467980	91,0370909

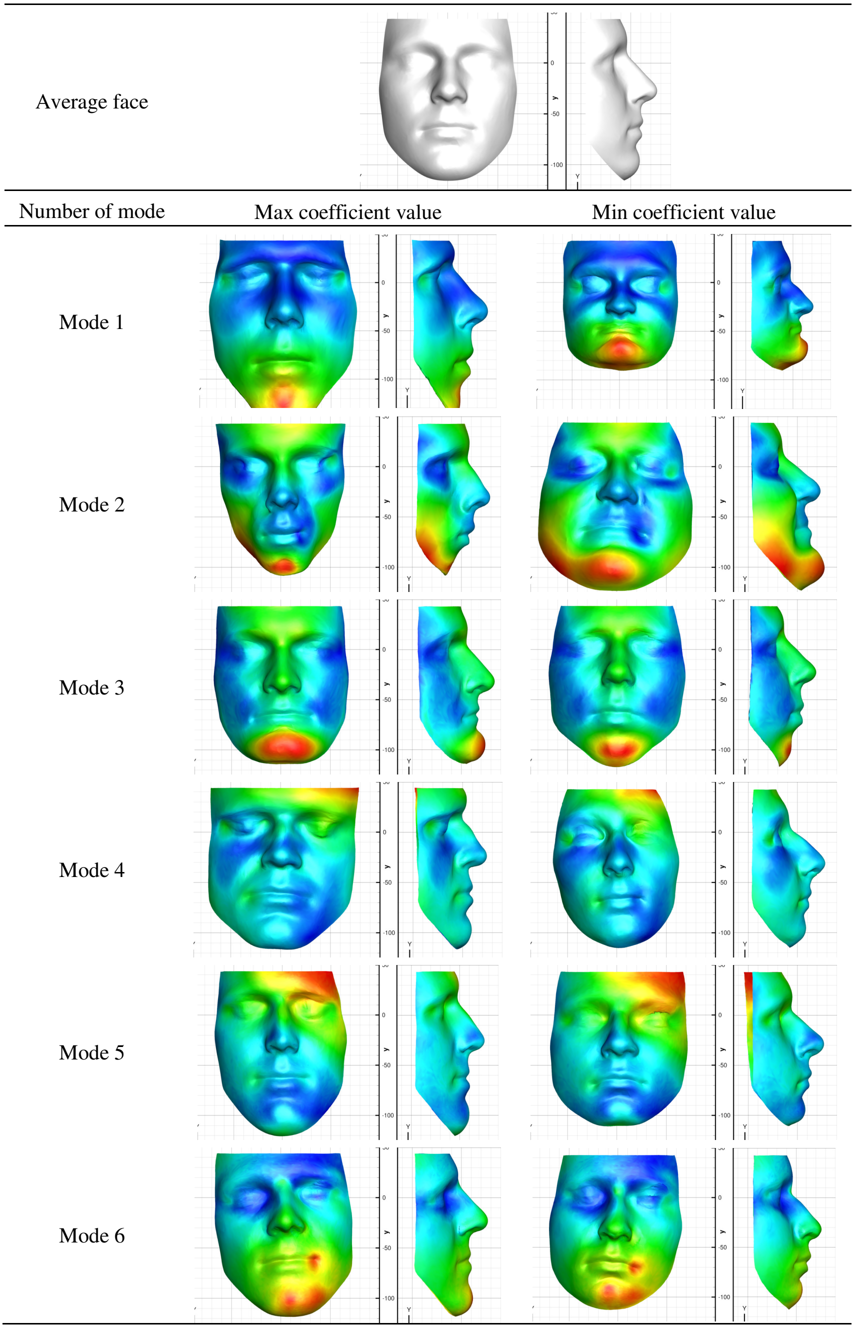

Fig. 5. Visualization of the PCA decomposition: average face and first six empirical modes

Modes describe the features of the faces. Individual modes geometric changes correspond to the largest in the analyzed objects. Another modes describes accordingly:

- Mode 1 - the general shape of the face - slenderness, scaling the size of the face and the size of the chin;
- Mode 2 - the general shape of the face - trapezoidal ovality, scaling the size of the face and chin lift;
- Mode 3 - mainly changing in chin area;
- Mode 4 - ovality or equivalently "squareness" of the face;
- Mode 5 and Mode 6 - "skewing" of the face (kind of asymmetry).

Further modes with lower energy determine another more local deformations (biometric features), in consequence more difficult for interpretation and description in words. The features described further modes may include for example: the depth of the beginning of the nose, the size of the mouth, the position of the mouth, size of the "hump" of the nose, etc.

5 Geometry Reconstruction of the Objects Based on PCA Modes

Any face collected in database and decomposed by PCA has unique set of coefficient values – equivalent of the identification code (Fig. 6). Each set of coefficient values describes individual shape of face and can be decoded and compared with the original data of the person. Also identical (for human eye view) monozygotic twins might be distinguished using these "faceprints" as well as 2D face biometrics systems or traditional fingerprints [5].

a) b)

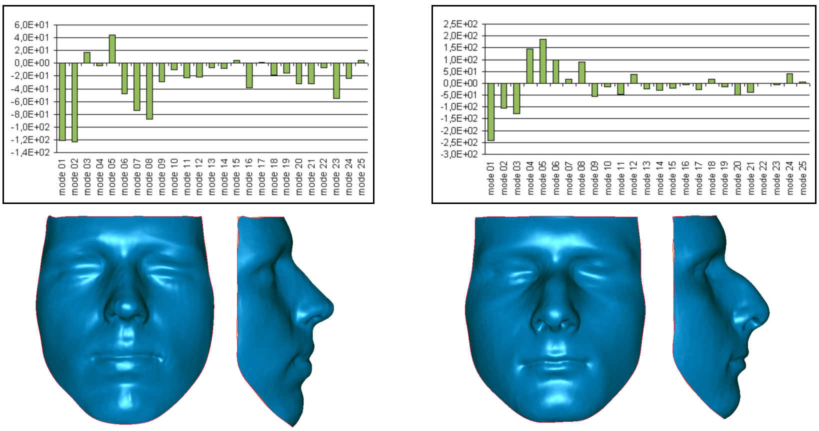

Fig. 6. Face "ID code" for two faces from database (each object is presented by – graph of coefficient values and 3D face model)

For randomly selected face from the database the reconstruction of the geometry was done. Presented reconstruction was performed with a different number of modes: 1, 4, 12 and 25 modes (Fig. 7 - row 1). For each reconstruction step - starting from the average face - a comparative analysis was made of the surface mesh of the model obtained in reconstruction (Fig. 7 – row 2) to the reference face model (original source 3D face model used for the analysis of PCA).

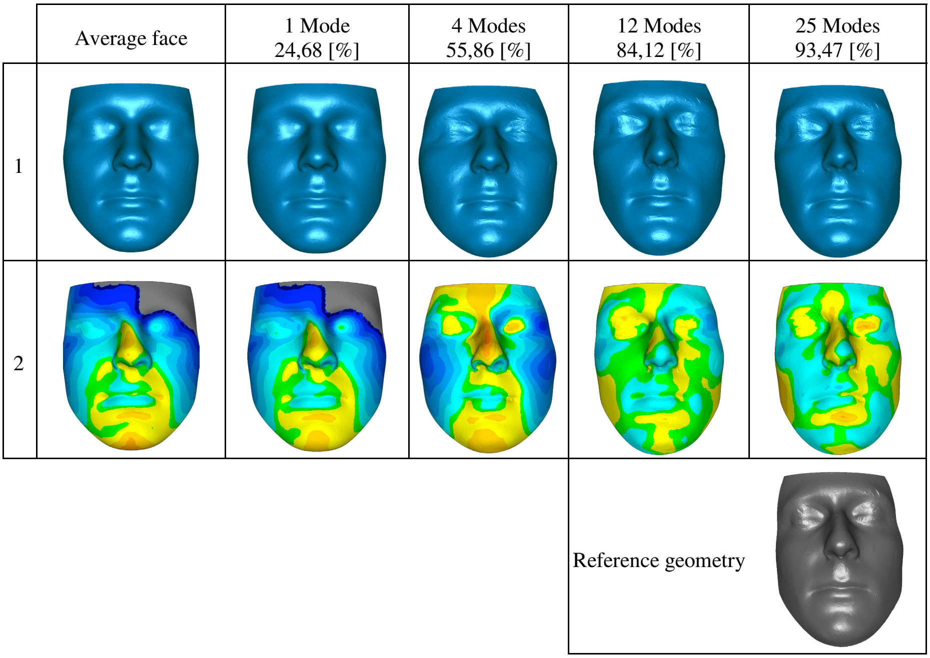

Fig. 7. Visualization of the reconstruction with using a different number of modes: 1) the surface mesh shape, 2) maps of the average deviation between a reference and reconstructed grid (bright color – max "+" deviation, dark color min "– "negative deviation).

The numerical values of the average distance and standard deviation of the compared surfaces (reference and reconstructed faces) are shown in Table 2 and illustrated on the graph (Figure 8).

Table 2. Results of the surfaces comparison of reference and reconstructed face

Number of the modes used for reconstruction	Average distance [mm]	Standard deviation [mm]
Average face	-1,630373	2,544203
1	-1,760347	2,515758
4	-0,918404	2,202656
12	-0,144863	0,825188
25	0,027492	0,577073

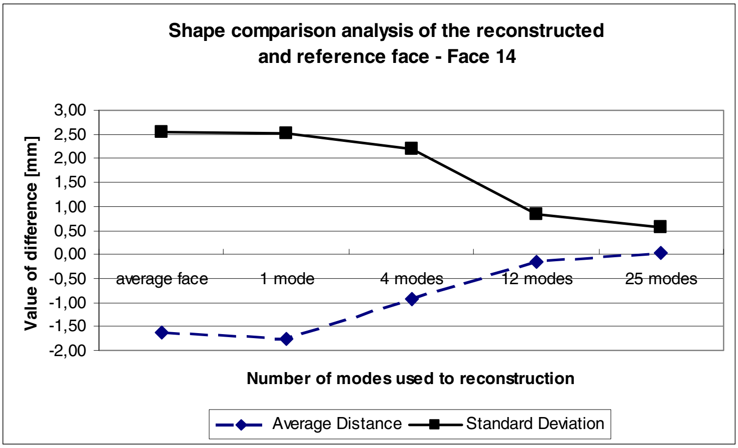

Fig. 8. The average distance and standard deviation diagram – results for comparison of reference and reconstructed geometry of the faces.

6 Summary

Three dimensional modal analyses of human faces have very interesting implications for future works with biometric systems. Such analysis makes possible the extraction of mean shape and geometrical features of biological object set.

Three dimensional systems are more powerful and stronger on any kind of fake than 2D systems which are used nowadays. Further is possible to add to data base additional information's (not only geometrical data) like e.g. thermal photo (map of temperature). Especially interesting results can be achieved with using 4-th dimension – time. Such "real time" systems can be applied for extraction individual movements of some regions of the face.

Presented method as the source of data-input, apply full 3D face information – instead of "control" points set (few nodal points in "golden triangle" area). The 3D geometry of the face (3D faceprint) is more complicated than "flat" image and by this way more proof onto fake than 2D face recognition systems.

The quality of the registration process has a fundamental importance onto results obtained in modal analysis. For 3D faces three-step registration process allows obtaining very precise final model. In presented article accuracy of registration process was better than accuracy of 3D scanning (0.05mm) used for data acquisition.

For testing of sensitivity level of proposed faceprints method the twin's faces can be used. Numerical experiments confirm that even the similarity faces of monozygotic twin's can be analyzed and coded with using PCA analysis.

Presented in article results of face reconstruction (with using different numbers of modes), showing that it is possible to obtain high quality 3d models with using low number of data. This is very important if such system will be work with data collected from all citizens of the country.

Additional mean shape and geometrical features of the faces (knowledge about shape and trends of deformations) can be used to create new three dimensional data base for forensics and police departments. Such 3D database can be important in anthropology, gives information about the changes that appear in the human skeletal structure in different populations or ages.

References

1. Anderson, R.J.: Security Engineering: A Guide to Building Dependable Distributed Systems. Wiley Publishing Inc., Indiana (2008)
2. Brett, A., Curless, B., Popović, Z.: The space of human body shapes: reconstruction and parameterization from range scans. ACM Transactions on Graphics (TOG) 22(3) (2003)
3. Bruce, D.A., et al.: Recognizing faces with PCA and ICA. Computer Vision and Image Understanding 91(1), 115–137 (2003)
4. Butlewski, M., Tytyk, E.: The assessment criteria of the ergonomic quality of anthropotechnical mega-systems. In: Vink, P. (ed.) Advances in Social and Organizational Factors, pp. 298–306. CRC Press, Taylor and Francis Group, Boca Raton, London (2012)
5. Gökberk, B., Salah, A.A., Akarun, L., Etheve, R., Riccio, D., Dugelay, J.L.: 3D face recognition. In: Guide to Biometric Reference Systems and Performance Evaluation, pp. 263–295. Springer, London (2009)
6. Hoffmann, H.: Kernel PCA for Novelty Detection. Pattern Recognition 40, 863–874 (2007)
7. Holmes, P., Lumley, J.: Turbulence, Coherent Structures, Dynamical Systems and Symmetry. Cambridge University Press, Cambridge (1998)
8. Jain, A.K., Ross, A., Pankanti, S.: A prototype hand geometry based verification system. In: Proceeding 2nd Int. Conf. Audio- and Video-Based Biometric Person Authentication, pp. 166–171 (1999)
9. Kuo, C.J., Huang, R.-S., Lin, T.-G.: 3-D facial model estimation from single front-view facial image. IEEE Transactions on Circuits and Systems for Video Technology 12(3), 183–192 (2002)
10. Lu, H., Plataniotis, K.N., Venetsanopoulos, A.N.: MPCA: Multilinear principal component analysis of tensor objects. IEEE Trans. Neural Netw. 19(1), 18–39 (2008)
11. Papatheodorou, T., Rueckert, D.: Evaluation of automatic 4D face recognition using surface and texture registration. In: Proceedings of the Sixth IEEE International Conference on IEEE Automatic Face and Gesture Recognition, pp. 321–326 (2004)
12. Rychlik, M., Stankiewicz, W.: Extraction of 3D Geometrical Features of Biological Objects with 3D PCA Analysis and Applications of Results. In: Naik, G.R. (ed.) Applied Biological Engineering – Principles and Practice, pp. 85–112. InTech (2012)
13. Rychlik, M., Stankiewicz, W., Morzyński, M.: Application of modal analysis for extraction of geometrical features of biological objects set. In: BIODEVICES 2008: Proc. 1st Int. Conf. Biomed. Electronics and Devices, vol. 2, pp. 227–232 (2008)
14. Rychlik, M., Stankiewicz, W., Morzynski, M.: Biological Objects Data Registration Algorithm for Modal (Low Dimensional) Analysis. In: HCI International 2013 - Posters' Extended Abstracts, Communications in Computer and Information Science, vol. 373, pp. 655–659. Springer, Heidelberg (2013)

15. Seitz, S.M., Curless, B., Diebel, J., Scharstein, D., Szeliski, R.: A comparison and evaluation of multi-view stereo reconstruction algorithms. In: 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, vol. 1, pp. 519–528 (2006)
16. Stankiewicz, W., Roszak, R., Morzynski, M., Noack, B.R., Tadmor, G.: Continuous Mode Interpolation between Multiple Operating and Boundary Conditions for Reduced Order Modelling of the Flow. AIP Conference Proceedings 1389(1), 94–97 (2011)
17. Xuerong, C., Jing, Z., Xiao, G.: Nonlinear fusion for face recognition using fuzzy integral. Comm. Nonlin. Science and Num. Sim. 12(5), 823–831 (2007)
18. Yörük, E., Dutağaci, H., Sankur, B.: Hand biometrics. Image and Vision Computing 24(5), 483–497 (2006)