Biological Objects Data Registration Algorithm for Modal (Low Dimensional) Analysis

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Abstract. Principal Component Analysis, a statistical tool allowing to create a low dimensional subspace basing on input data, finds many applications in biomechanics. The PCA requires the same topology (mesh connectivity, number of nodes) for all objects in database. To achieve this, each new object added to database must be registered. In this article the finishing registration procedure, based on own software and created especially for biological data sets, is presented. The study of registration process for 3D input data (faces and hands) for PCA is discussed.

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

1 Introduction

Advanced numerical tools significantly increase the possibilities of existing methods of data analysis and give new potential in disciplines like bioengineering or biometrics. In biometrics the identification of people might be based on different input data, like the shape of the face [2, 13], hand [4, 14], or whole human body [1].

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.

In the case of hand-based verification of individuals, usually overall structure, 2D shape (silhouette) and proportions of the hand (length, width and thickness of hand, fingers and joints) [10] are measured and analyzed. Hand geometry biometrics systems, measuring up to 90 parameters in 2D space.

Insufficient reliability of the currently used 2D recognition techniques (photos contain less information then the 3D surface) stimulates interest in 3D techniques.

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 [7, 8].

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2 PCA Analysis and 3D Input Data Acquisition of Biological Objects

For reconstruction of the 3D geometry, decomposition based on Principal Component Analysis (PCA) can be used. 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 [3]. Eigenvectors of this matrix (PCA modes) represent the geometrical features (shape) of the object, as well as additional information like physical features (density), texture or temperature map [9]. Only a small number of first modes carry most information, therefore each original object can be reconstructed by a mode basis truncated to the most dominant principal components.

The data input for numerical experiment was obtained by using the 3D structural light scanner. The two groups of biological models were measured: set of human faces and set of human hands. Each input object was scanned and 3D surface model (50k triangles mesh) was computed. During measurements of hand geometry the special hand holder (for the appropriate and repeatable fingers positioning) was used. The shape of the hand holder was comparable as used in hand silhouette 2D scanners [4]. In this work 100 faces of different persons (age: 22-24) with neutral expression and 100 human hands was acquired.

3 Biological Objects Data Registration Algorithms

The registration process used for the 3D model of face is performed in three stages.

First stage – preliminary registration – involves making a series of affine transformations (shift, rotation and scaling) on scanned face so that its position in a coordinate system is analogous as the reference face (fig. 1. a).

The second stage – elastic registration – consists of five steps:

1. detection of edge elements lying on the boundary of the face (fig. 1. b).
2. automatic detection of 16 specific points on the surface of the registrant (placed on the base) face (Fig. 1. c) defining: eyes, nose, mouth, beard / chin, basic on the curvature of the selected cross-sections of the 3D model.
3. The displacement of boundary curve points of reference grid onto new position on registrant grid, holding relative distance from the beginning of the curve.
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 - steps 3); 4) - using the method of Shepard (Inverse Distance Weighting) [11].

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. For each node (deformed in the second stage) reference grid is searched the next node on the registration grid - whose coordinates are assigned to the reference grid node (Fig. 1. d). In the case of the face registration this step leads to a better fit mesh in areas which are not described by the characteristic points and between of them (such as the cheeks and forehead, the curvature of the nose). The developed own numerical tool is based on kd-tree searching algorithm [5].

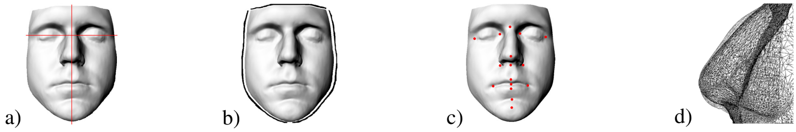

Fig. 1. Face elastic registration: a) origin point, b) detection of the edges curves, c) detected points, d) surface triangle grids: of elastic *(black)* and finishing registration *(light gray)*

The result of the applied registration 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.

For the 3D hands models, the special rigid registration software was eliminated. This step was done by using special hardware – hand holder.

The first step of non-rigid registration consists of the adjustment of the positions of fingers (phalanges and metacarpals). The skeleton nodes' positions are modified by genetic algorithm [12], resulting in a population with varying genotype (positions of skeleton nodes). For each individual (deformed skeleton) solid mesh representing base geometry is deformed using Finite Element System solving Hooke's law. Resulting deformed meshes are compared with respect to the new mesh being registered, and the objective functions, based on error measure, are computed. The whole process is depicted in Fig. 2.

After the adjustment of finger positions the widths and lengths are to be changed.

This process is done using in-house CFD (computational fluid dynamics) solver. The governing equation (1) is incompressible Navier-Stokes equation in penalty formulation [6] with additional volume forces, discretized using Finite Element Method. The forcing (source segment) depends on the difference between two monochrome slices – from registered and base meshes [8]:

$$\dot{V}_i + V_{i,j}V_j - \frac{1}{\mathrm{Re}}V_{i,jj} + \frac{\varepsilon-\lambda}{\rho}V_{j,ji} + (f-g)f_{,i} = 0 \qquad (1)$$

where ρ is fluid density, V_i - velocity component, Re - Reynolds number, λ - bulk viscosity. The parameters ε and λ are used to control the fluid compressibility, f is the base object and g is the target object (input model). The CFD registration is performed on a set of equidistant slices perpendicular to the first principal axes of the phalanges and a set of slices through the metacarpus perpendicular to the x axis.

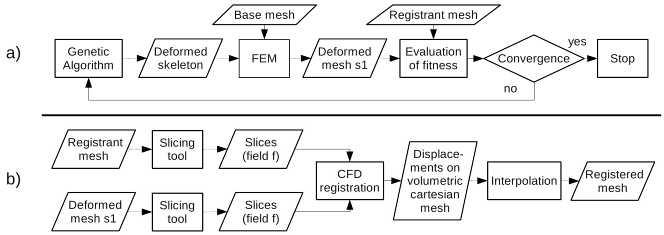

Fig. 2. Algorithm of the hand registration: a) skeleton based registration, b) fluid registration

The final step is the interpolation of displacements from CFD structured (Cartesian) mesh onto the (deformed) base mesh. The value of standard deviation between source and registered hands was 0.83mm and average distance 0.11mm.

4 Principal Component Analysis of 3D Biological Objects

For prepared databases of human faces and hands the PCA was performed. The result of this operation is the mean object, modes and coefficients values. To reconstruct 90% of information about decomposed geometry, first 19 modes for faces (Fig. 3 top) and first 10 modes for hands (Fig. 3 bottom) have to be used.

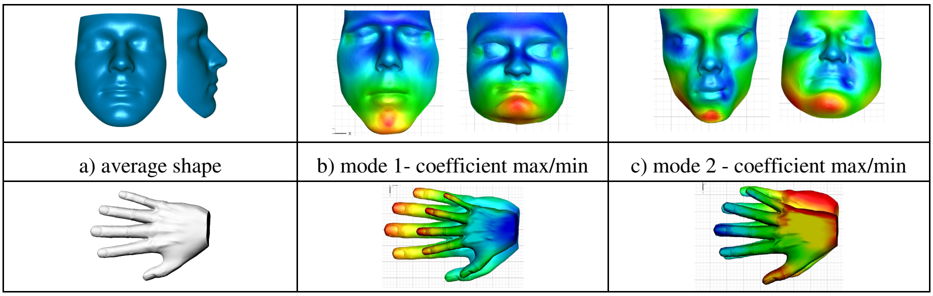

Fig. 3. Visualization of the average value and first two empirical modes of faces and hands

5 Summary

The quality of the registration process has a fundamental importance onto results obtained in modal analysis. In the article authors present two specialized algorithms – based on own software code – for three-dimensional registration of biological objects: faces and hands.

For 3D faces three-step registration process allows obtaining very precise final model. In the case of faces described in this article accuracy of registration was better than accuracy of 3D scanning (0.05mm) used for data acquisition.

For 3D hands skeleton-based and CFD registration were performed. The lower accuracy obtained in this case is due to lower quality of input data from 3D scanner. For evaluation of registered databases the brief results of PCA was shown.

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