ESTIMATION OF ASYMMETRY IN 3D FACE MODELS

Natalya Dyshkant and Leonid Mestetskiy
Department of Computational Mathematics and Cybernetics, Lomonosov Moscow State University, Moscow, Russia

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Abstract: This paper proposes a new estimation of facial asymmetry in 3D face models of humans and an algorithm to compute it. We consider models derived by 3D scanning method. Each model is given as a cloud of points in 3D space and can be considered as a discrete single-valued function of two variables. We present an approach for constructing a disparity measure between original face model and its reflected model. Main stages of proposed algorithm are construction Delaunay triangulations of two models and general Delaunay triangulation, function interpolation on basis of triangulations localization in each other and comparison of functions on separate triangles of general triangulation. Further using elementary manipulations of reflected model algorithm searches such position that two models constitute a maximum matching so that the corresponding disparity measure will be minimal. We carry out computing experiments on database consisting of about 200 face models. These experiments have indicated that the proposed estimation is stable for different models of one and the same person.

1 INTRODUCTION

A human face is only *approximately* bilaterally symmetrical with respect to the plane that divides it into two halves. The aims of this paper are to define a degree of such approximation, i.e. degree of *facial asymmetry*, and to propose an algorithm to compute it. A problem of facial asymmetry estimation appears in such applications as preventionism of child eyesight anomalies (Knizhnikov, 2005), cosmetology (facial surgery), psychological and medical (including dental) research, etc. Hypothesis checking of correlation between diagnoses made by ophthalmologist and measures of facial asymmetry is described in (Murynin, 2004). Also facial asymmetry can improve results of biometric identification (Mitra, 2007) and facial expression recognition (Teng, 2006) algorithms.

Current 3D imaging technologies allow to receive three-dimensional models of human faces in real time.

A model derived by 3D scanning method (see Figure (1)) is presented as a cloud of point in 3D space and can be considered as a discrete single-valued function of two variables $z = F(x,y)$. The z axis represents front-back displacements of the head. Domain of each function is a certain discrete set $G = \{x,y\}$.

It is proposed to compute sum or mean value of height difference between points of original and reflected 3D models (Liu, 2003) in papers related to facial asymmetry estimation. This means that values of two functions (corresponded to original and reflected models) are known in each point of the set G. Actually models derived by 3D scanning don't initially have such property. So a shortage of proposed estimations is that the preprocessing is required. It can cause loss of observational accuracy. Moreover, it is impossible to use such estimations for computing disparity measure between two models when we search such position that models constitute a maximum matching. Main shortages of existed asymmetry estimation methods are low numerical efficiency or loss of source data accuracy. Therefore the problem of facial asymmetry estimation is still an urgent problem.

In this paper we propose a new estimation of facial asymmetry that is computable directly from 3D face model and an algorithm to calculate it. We present an approach for constructing a disparity measure between original face model and its reflected model. Let us remark that functions of original and reflected models are defined on two *different* discrete sets. We use elementary manipulations of reflected model for searching such its position that corresponds to minimum of disparity measure. Finally, we define quanti-

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tative asymmetry estimation of 3D model as the minimum disparity measure between this model and its reflection.

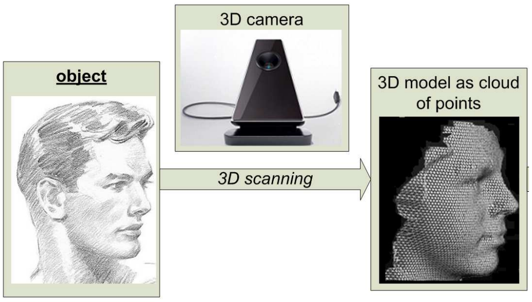

Figure 1: Receiving of 3D model of human face.

Now we introduce the following concept. Disparity measure between two models is a spacial volume between the corresponding surfaces. It is also allowed to use ”weighted” volume. In this case similarity of some surface patches will have greater weight than similarity of others. The mathematical problem has the following content. Suppose surfaces are given by functions $f(x,y)$ and $g(x,y)$ on discrete sets G_1 and G_2 respectively, G_1 and G_2 are contained inside a certain general rectangle R, $\hat{f}(x,y)$ and $\hat{g}(x,y)$ are continuous on R analogs of functions $f(x,y)$ and $g(x,y)$, that are derived by interpolation: $\forall(x,y) \in G_1 \quad f(x,y) = \hat{f}(x,y)$ and $\forall(x,y) \in G_2 \quad g(x,y) = \hat{g}(x,y)$, function $\mu(x,y)$ defines weight of surface fragments in accordance with significance of their similarity, $\Delta(f,g)$ — disparity measure between functions; then we have:

$$\Delta(f,g) = \iint_R \mid \hat{f}(x,y) - \hat{g}(x,y) \mid \mu(x,y)\, dxdy.$$

It is required to design a numerically efficient method to compute this measure that provide good accuracy. We can obtain acceptable accuracy using piecewise-linear approximation of surfaces by triangles of Delaunay triangulations of discrete point sets. Also, there is a problem of efficient computation of measure for functions when triangulations are constructed on different sets of nodes.

Our method based on constructing of new Delaunay triangulation on union of two discrete sets. As the union process can be implemented in linear time (Mestetskiy, 2004) then the total time to compute the proposed measure is comparable with time of constructing Delaunay triangulation, i.e. $O(N \log N)$, where N — the total amount of points in two sets. Consequently, the proposed method allows to avoid quadratic search in surface comparison that determines its advantage and novelty.

2 3D FACE DATABASE

Three-dimensional models used in this research were derived by 3D scanner developed in ”Artec Group company”. The database contains 191 models of 8 different persons. All persons have a neutral facial expression.

Each model is represented as collection of points with coordinates (x,y,z) in space. All distances have a scale of one to one, i.e. correspond to real sizes of a human face. Amount of points in models changes from 1000 to 3000, and its mean value is about $1500-2000$.

Each model has been normalized in such a way that the end of nose coincides with coordinate origin, the z axis represents front-back displacements of a head, the y axis — up-down displacements (see Figure (2)). So we may assume that model is bilaterally located with respect to the Oyz plane. Note that the described normalization is assumed only as approximate.

3 ALGORITHMS

General scheme of presented approach is given on Figure (2).

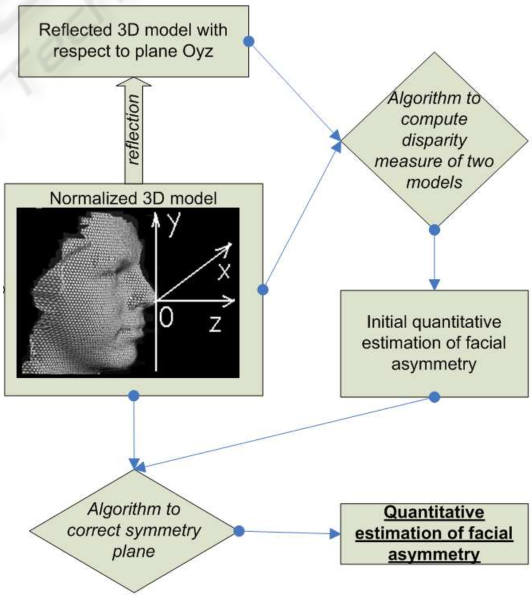

Figure 2: General scheme and main stages of presented approach.

After model normalization in the coordinate system we construct its symmetrical reflection.

The proposed method of computing a quantitative estimation of facial asymmetry consists of two stages:

1) computing initial estimation as disparity measure between original and reflected models and 2) correction of symmetry plane of a model.

3.1 Computing Disparity Measure between Two Models

Main steps of algorithm for computing disparity measure between two models are:

1. Delaunay triangulation construction of each discrete set;
2. location of each discrete set in triangulation of the other set;
3. linear interpolation of each function on the other set using barometrical coordinates;
4. constructing of general triangulation of two discrete sets on basis of merger algorithm;
5. function comparison on particular cells of the general triangulation. Positional relationships of the spatial triangles given by functions are analyzed during this comparison .

3.2 Searching Symmetry Plane of Model

As we assume that model's normalization in coordinate system is approximate, we try to transform coordinates using small shifts and rotations by small angles about the coordinate axes. One process of surface comparison may be implemented very efficiently so it is possible to organize a guided search of such discrete set's transformation that provides the maximum matching. The aim of this correction is to find such position of the *Oyz* symmetry plane that the value of quantitative asymmetry estimation is minimum.

It can be assumed that we minimize estimation not by all six parameters of elementary manipulations but only by three of them because it is obvious that shifts along the y and z axes doesn't have an influence on asymmetry estimation and we also don't consider rotation about the x axis as we have full face photography.

We make small transformation of the coordinate system: shift along the x axis, then rotation by the angle φ about the z axis and, finally, rotation by the angle ψ about the y axis. In such a way G_1 will transform to $G_1(x,\varphi,\psi)$ and G_2 — to $G_2(x,\varphi,\psi)$. f and g will also be transformed. Denote by $\Phi(x,\varphi,\psi) = \Delta(f(x,\varphi,\psi), g(x,\varphi,\psi))$ disparity measure between transformed surfaces.

The problem of searching the optimal symmetry plane reduces to minimization of $\Phi(x,\varphi,\psi)$. For this purpose we use alternating-variable descent method combining with algorithm of golden section.

Notice that function Φ is ravine, i.e. change δ of variables φ or ψ causes a greater change of function value than the same change δ of variable x. We are taking into account this property of function during minimization procedure.

In table 1 there are values of initial estimation of facial asymmetry (after stage 1) and estimation after symmetry plane correction for 4 different face models of one person. To understand significance of these values let us remark that volume of fluid in tablespoon is approximately equal to 15 000 cmm.

Table 1: Initial and corrected estimations of facial asymmetry.

Model's number	Initial asymmetry estimation (cmm)	Corrected asymmetry estimation (cmm)
1	47 466,361	24 072,518
2	49 192,110	25 205,272
3	43 473,767	24 421,316
4	46 280,040	22 263,813

An optimal shift along the x axis is about $2,4-2,6$ mm for models from the database, values of optimal angles about the y and z axes are about $0,015$ rad.

4 COMPUTING EXPERIMENTS

The described method for comparison of models was implemented, and there also has been made multiple computing experiments for all stages of algorithm.

As experimental estimations have shown, each of stages, except stage of triangulation constructions, is implemented in linear for number of mesh nodes time. Delaunay triangulation is implemented in time $O(N \log N)$. Triangulation construction defines computational complexity of the proposed approach.

Running time for different stages of algorithm during comparison of human's face surfaces are adduced in table (2). The three-dimensional portraits consisting approximately from 3 000 points were used here. Computing experiments were conducted using AMD Athlon 2 600+ processor and 512 Mb operative memory.

Results of computing experiments on the database demonstrate that the proposed estimation is stable for different models of one and the same person.

The experiments indicate that the initial estimation varies strongly for several models od the same person. Nevertheless the stage of symmetry plane cor-

Table 2: Running time for different stages of algorithm.

Stage of algorithm	Time (sec)
Construction of two triangulations	0,124
Construction of two MSTs	0,203
Location of triangulations	0,015
Function interpolation	$< 0{,}001$
Construction of general triangulation	0,109
Computing disparity measure $\int \mid F_1 - F_2 \mid$	0,031
Total time	0,497

rection increases many times stability of the estimation.

In average for the database spread in values of initial asymmetry estimation is 36 000-40 000 cmm. On the other hand, spread in values of corrected asymmetry estimation is 9 000-11 000 cmm.

To estimate approximation accuracy of real head model we perform the following experiments. We compute change of asymmetry estimation of initial model and model received by thinning, i.e. point rejection of the corresponding discrete set. Points for rejection are selected randomly. Suppose make rejection of about 1 500 points of models consisted of approximately 3 000 points; then asymmetry estimation will not strongly change. After rejection of more amount of points the asymmetry estimation begins increasing (see Figure (3)).

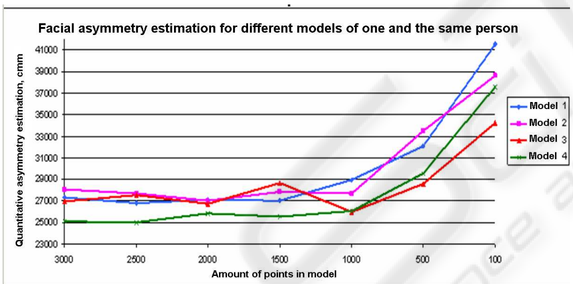

Figure 3: Facial approximation accuracy.

5 CONCLUSIONS

In this paper we define a quantitative estimation to compute facial asymmetry directly from 3D face model. We introduce disparity measure between two models and compare original face model and reflected model. We propose algorithms to compute the estimation and to determine the optimal symmetry plane of model.

The proposed method has the following advantages: computing efficiency, possibility of paralleling. Besides, the described approach possesses some universality in comparison with others as it is suitable for comparison of any models given by functions on discrete sets. The proposed measure can be adapted for each concrete application, for example, by means of introducing measure on a surface.

The results of computing experiments carried out on the database show stability of the proposed estimation for different models of one and the same person and numerical efficiency of the algorithm.

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