Shape analysis of the human zygomatic bone - surface registration

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Introduction

Landmark-based shape analysis is heavily dependent on reliably placed reference points. Depending on the analysed bone structure, such points might be difficult to define. As a consequence, shape information is lost. Our goal is to establish a procedure to fit the surface mesh of a reference specimen onto a sample of surface meshes representing the osseous zygomatic structure.

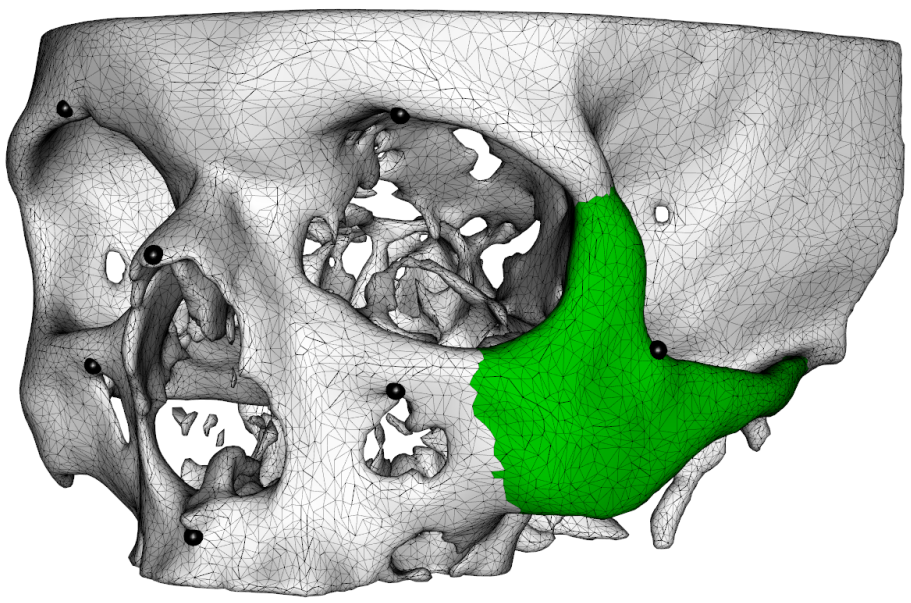

Fig. 1: Manually placed landmarks on reference mesh. The region of interest is marked green.

Approach

The method proposed by us uses Gaussian smoothed displacement vectors (Moshfeghi et al.1994). Landmarks are only required to establish an initial registration within a common coordinate system.

Algorithm

0. clean target mesh (removal of isolated pieces) and decimate to an average edge length of 1.4 mm
1. rotate reference onto target
2. perform ICP-matching
3. elastic matching (40 iterations)
a) project each vertex of the refrence mesh onto the target mesh and vice versa
b) discard displacement vectors for closest points pointing into the wrong direction (for angles between normal vectors > 90°), or if the angle between the displacement vector and the normal exceeds 45°.
c) smooth the displacement vectors by applying Gaussian smoothing, based on each vertex' neighbourhood (to reduce computation time, vertex neighbourhoods are restricted to the closest 120 vertices). With each iteration the deformation becomes more elastic, by subsequently down-weighting more distant displacment vectors.
d) smooth the surface to prevent mesh folding (Vollmer 1999)
e) parameters used in this study:
$\sigma_0 = 40$; f=1.1; γ =2 (cf. Moshfeghi et al.1994)

Result

All meshes are constituted by the same amount of corresponding vertices. Thus, a region of interest (ROI) can also be defined *after* the registration on the reference.

All computations are performed on the mathematical platform **R** (for code see contact information).

Application

- The algorithm is applied to **200** triangular meshes representing human mid-facial skull, generated from clinical CT-scans
- the initial registration is based on **8** reference points (see Fig. 1)

Problem statement

Conducting a shape analysis of the human zygomatic bone, one has to deal with the fact that only few reliable landmarks can be defined. Thus, the largest part of the zygomatic shape can not be grasped by traditional landmark-based analysis. To overcome these restrictions, a registration procedure is presented that is based on a semi-automatic surface-matching algorithm.

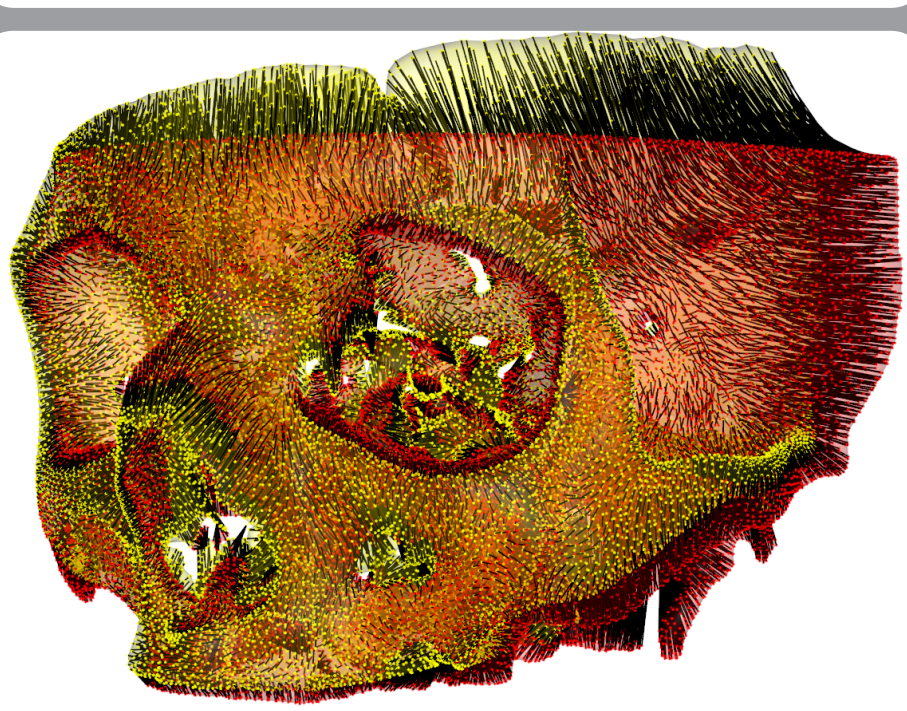

Fig. 2: Displacement vector field between two superimposed surface meshes.

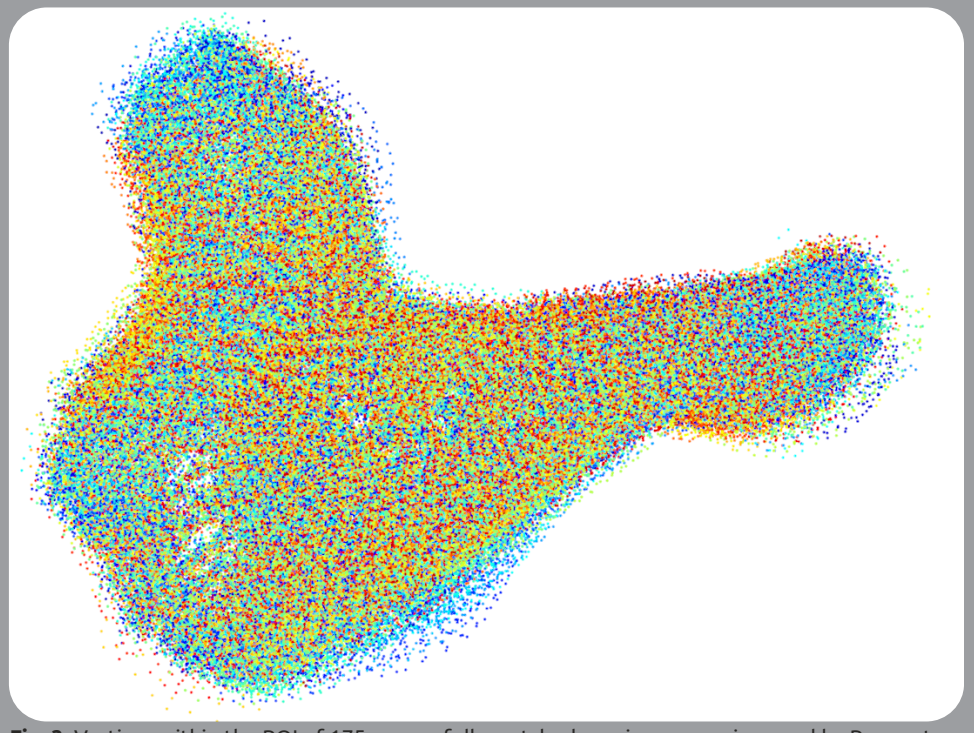

Fig. 3: Vertices within the ROI of 175 successfully matched specimen superimposed by Procrustes-registration.

Results

After the matching process, those vertices within the ROI are extracted and can be used as coordinates, corresponding between the specimen in the sample.

Caveats

Meshes must be clean and not containing inner layers because this may cause unwanted distortions. Of 200 meshes, 25 had to be excluded due to this distortion. Also, the ROI must be distant from regions that do not correspond between specimen (e.g. if one mesh includes the mandible, where the other does not).

References:
Moshfeghi M, Ranganath S, Nawyn K. 1994. Three-dimensional elastic matching of volumes IEEE Transactions on Image Processing: A Publication of the IEEE Signal Processing Society 3:128-138.
Vollmer J, Mencl R, Müller H. 1999. Improved Laplacian Smoothing of Noisy Surface Meshes Computer Graphics Forum 18:131-138.

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