Statistical Mesh Shape Analysis with Nonlandmark Nonrigid Registration

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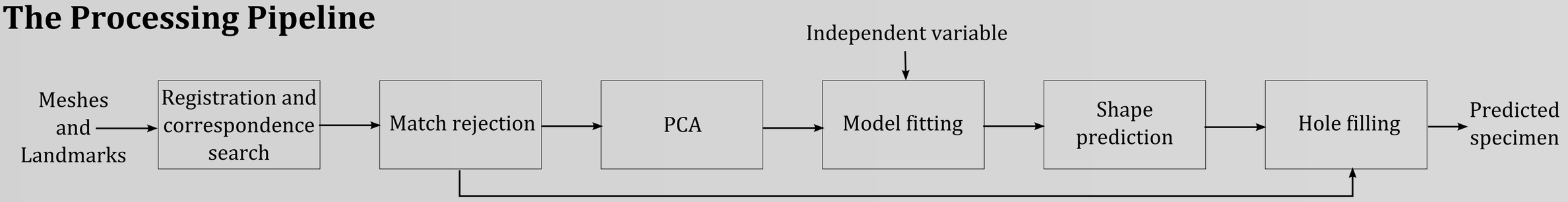
The analysis of shape represented as surface meshes is an important tool in anthropology and biomedicine for the study of aging, post-treatment development or sexual dimorphism. Most approaches rely on nonrigid registration using manually placed homologous landmarks, it is however often the case that some regions cannot be landmarked due to the lack of clear anatomical features. We therefore present a method of analyzing and visualizing the variability of a set of surface models that does not rely on landmarks for feature matching and uses coherent point drift (CPD), a nonrigid registration algorithm, instead. Our approach is based on the topology transfer of one arbitrarily selected base mesh to all other meshes with the use of CPD. The procedure ensures the identical meanings of corresponding vertices across the sample and allows the use of multivariate statistics even with shapes that would be difficult to process with methods that rely on landmarks for feature-matching.

The Processing Pipeline

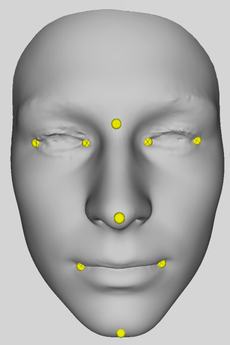


Addressed Issues

In many studies, landmarks cannot be placed **evenly or densely** enough to properly fit a deformation in feature matching.

Inconsistent **manual mesh trimming** and noisy regions cause unwanted variability.

We need a processing pipeline similar to [HBH01] robust to these issues.



Rigid Registration

Keep only **shape variables** by normalizing individual translation, rotation and size; however store specimen size for use in prediction phase.

Perform generalized Procrustes analysis (GPA) on landmarks.

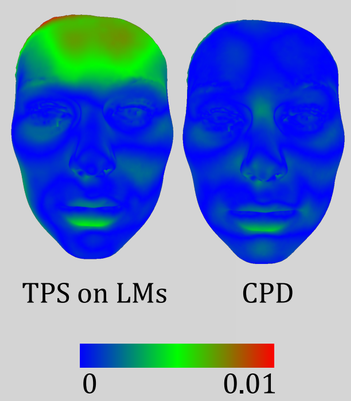
Use the transforms from GPA to align the meshes.

Vertex-Point Matching

A combination of **nonrigid** (NR) registration and **raycasting/closest point** search.

Coherent point drift [MS10] is used for NR registration, yields tighter alignement than deformation fitted to landmarks.

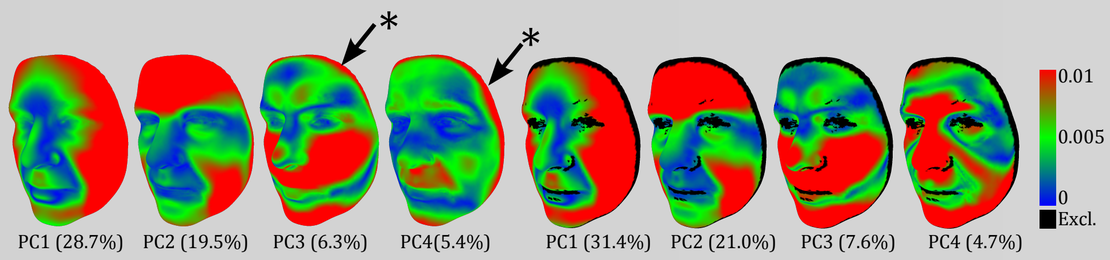
Fast implementation in CUDA - CPD iteration rougly 10x faster.



Correspondence Rejection

Incorrect vertex-point matches are generally caused by inconsistent mesh trimming or noise and can cause **unwanted variability*** in PCA.

Overstretched or collapsed triangles are the result of these mismatches, these are **excluded** from PCA.



PCs without rejection PCs with rejection (k_{bad}=0.05)

Shape Prediction and Hole Filling

Restore specimens' size if a study of **form** (shape+size) is desired.

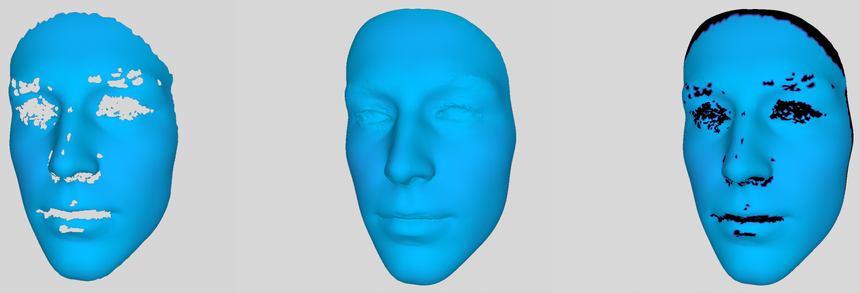
PCA is performed on the vertex locations that were not removed.

A model is fitted to the PC scores and explanatory variables with **linear** or **quadratic** multivariate regression..

Prediction will not handle **excluded vertices**, they must be approximated separately.

Displacements of vertices on the boundaries of excluded regions are used to fit a thin plate spline (TPS).

Excluded vertices of mean mesh are transformed using that TPS.



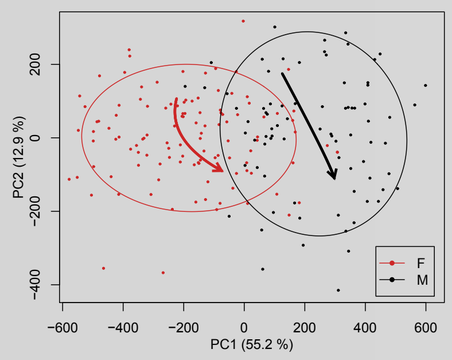
Without Filling Holes Filled Holes Filled and Marked

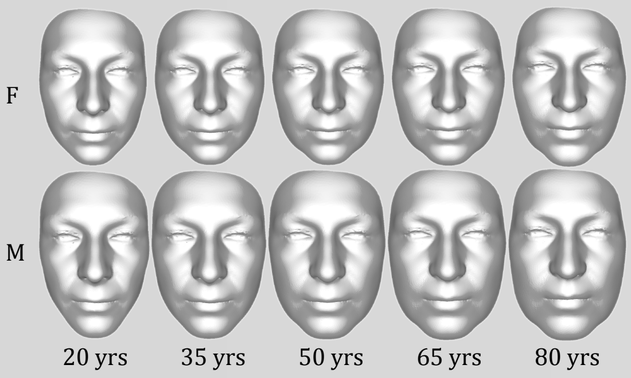
Applications

Studies of shape variability and prediction of shape in biology, anthropology, medicine and forensic sciences.

Example. Modeling the aging of human facial form (20-80 yrs).

Aging trajectories were estimated with quadratic regression and are shown in the space of the first 2 principal components.





Example. Modeling the growth of palate in infants after receiving a surgery correcting for unilateral cleft of lip and palate.

Growth trajectories can be also visualized using color maps.

Future Work

Modeling high-frequency content such as wrinkles and folds.

Explore the options of eliminating the need for landmarks altogether.

References and Acknowledgments

[HBH01] HUTTON T., BUXTON B., HAMMOND P.: Dense surface point distribution models of the human face. Proceedings of IEEE Workshop on MMBIA (2001), 153-160

[MS10] MYRONENKO A., SONG X.: Point set registration: coherent point drift. IEEE transactions on pattern analysis and machine intelligence 32, 12 (Dec. 2010), 2262–75.

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