PROBABILISTIC JOINT FACE-SKULL MODELLING FOR FACIAL RECONSTRUCTION

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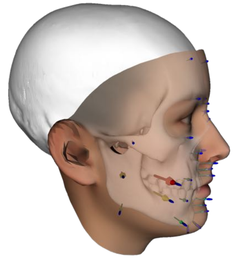
Problem: Creating a joint shape model from independent statistical shape models



Disaster Victim Identification (DVI) - Given only the skull shape, how can we identify the correct face within a face database? We propose to solve this problem by obtaining the joint face-skull probability distribution from independent Statistical Shape Models (SSM) of the human face [1] and the human skull [2]. The models are joint with independent tissue-depth information [3] using Markov Chain Monte Carlo (MCMC).

Contribution

- Showing that facial reconstruction can be formulated as a conditional distribution of plausible face shapes given a skull shape
- Showing how skull pixels can easily be identified in an MRI
- Solving co-registration of independent statistical shape models

Statistical Shape Models

Our Statistical Shape Models (SSM) are created as Gaussian Process Morphable Model (GPMM) [4]. The face and skull models are created independently from sets of example shapes.

Mean shapes and the first 2 principal components (PC) of the face and skull shape models.

References

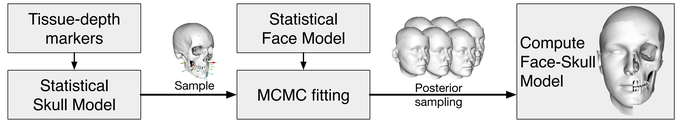
[1] P. Paysan, R. Knothe, B. Amberg, S. Romdhani, and T. Vetter, "A 3d face model for pose and illumination invariant face recognition," in *Advanced video and signal based surveillance, 2009. AVSS'09. Sixth IEEE International Conference on*, pp. 296–301, IEEE, 2009.

[2] M. Lüthi, A. Forster, T. Gerig, and T. Vetter, "Shape modeling using gaussian process morphable models," *Statistical Shape and Deformation Analysis: Methods, Implementation and Applications*, p. 165, 2017.

[3] C. N. Stephan, "The application of the central limit theorem and the law of large numbers to facial soft tissue depths: T-table robustness and trends since 2008," *Journal of forensic sciences*, vol. 59, no. 2, pp. 454–462, 2014.

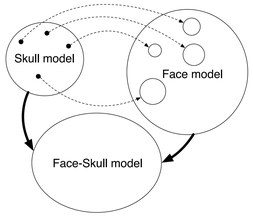
[4] M. Lüthi, T. Gerig, C. Jud, and T. Vetter, "Gaussian process morphable models," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 2017.

Combining the independent models



To combine the models we first estimate the face distribution for random skull samples using MCMC (see separate box). The joint face-skull model is computed by building a dataset from the individual skull samples and a subset of face samples from their respective posterior distributions.

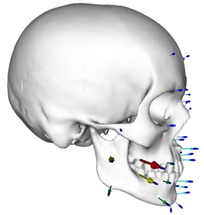
Posterior Face distribution - General Idea



The joint face-skull distribution is modelled as a multivariate Gaussian distribution over face and skull shape.

$$\Gamma_F, \Gamma_S \sim \mathcal{N}(\mu_F; \mu_S, \Sigma_F; \Sigma_S)$$

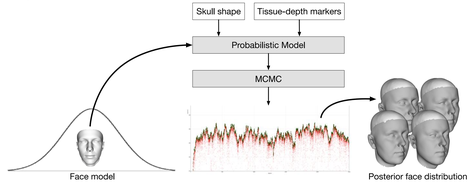
Placing Tissue-depth markers



Tissue-depth markers are placed on the skull with position, depth and variance according to tissue-depth measurements [3]. A total of 40 tissue-depth markers are placed on the skull.

Posterior Face distribution

The full distribution of face shapes over a given skull shape is estimated with MCMC by sampling random face shapes from the face shape model.

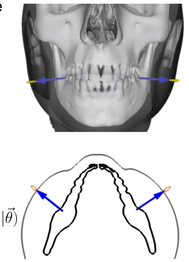


Simulating the Joint Face-Skull Distribution

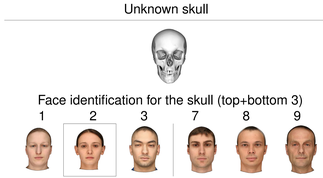
The face distribution for each skull shape is defined by multiple likelihood terms:

- Tissue-vector intersection depth
- Tissue-vector symmetry
- Face in skull detection
- Point correspondence (in a single point)

$$P(\vec{\theta}|D^{tvi}, D^{sym}, c, D^{cs}) \propto P(\vec{\theta})P_{tvi}(D^{tvi}|\vec{\theta})P_{tvs}(D^{sym}|\vec{\theta})P_{fs}(c|\vec{\theta})P_{cs}(D^{cs}|\vec{\theta})$$



Experiment & Results - Face identification given a skull



The 3D face database is projected into the combined conditioned model. The faces are ranked according to their likelihood to fit the skull.

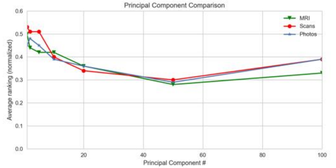
The number next to the experiment (listed below) mentions the number of faces in the face database.

Results of the ranking experiment with 9 skulls. In all the experiments we get a consistent top 30% average ranking. The number next to the experiment mentions the number of faces in the face database.

Experiment	μ	μ norm	σ	Min	Max
MRI (9)	2.44	**0.27**	1.67	1	5
Scan (9)	2.89	**0.32**	1.54	1	5
Photo (9)	3.00	**0.33**	1.80	1	6
Scan (306)	91.89	**0.30**	44.23	26	159
Photo (106)	31.56	**0.29**	27.03	4	82

Model evaluation

Evaluation of the number of PC's used in the face identification experiment. We find that around 50 PC's gives the best result. From this, we conclude that it is not only the size but a combination of different skull shape characteristics which are needed to identify the likely faces.



MRI Skull Segmentation: Conditioning the joint model on a face