Traveling Optical Scanner - Case Study on Brazilian Skulls

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Contribution

A fast, highly portable and low-cost 3D scanning modality based on structured (visible) light, suitable for recovering detailed morphological information from archaeological specimen, is proposed by the authors. This setup does not inflict any material damage such as DNA degradation, and the deviation between optical and micro-CT scans is on the sub-millimeter level.
Advantages of having 3D scans are:

- Advanced morphological modeling possible
- Reduced risk of damage to original specimen
- Shape and appearance is documented
- Easy to share among researchers
- Can be made available to the public

The authors demonstrate the use of our system in a small case study on the collection of 8500-year-old human skulls, which were recovered from the Sumidouro cave in Brazil by the Danish scientist Peter Wilhelm Lund around 1845: The collection was digitized and the morphological features were analyzed based on manually annotated landmarks.

Optical Scanner

A structured light scanner meets the requirements of having a high precision, and of being non-destructive. The setup [1] provides a single point cloud for a complete 360° scan. The mean point-wise distance from CT to optical scan is 0.2425 mm for a fox skull, and 0.3957 mm for a bulldog skull.

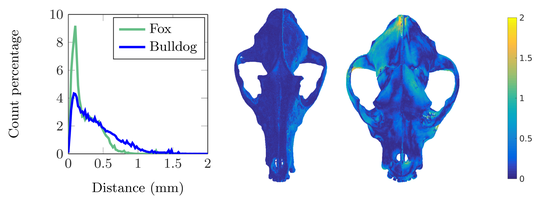

Figure 1: Left: Histogram of point-wise distances from CT to optical scan for a fox and bulldog skull. Right: Point-wise distances on the skulls. Larger deviations occur at the areas that are most likely to be occluded.

Case Study - Skull Scans

The scanned specimen include 24 skulls from the Brazilian collection at the Natural History Museum of Denmark. All skulls are incomplete, and 9 skulls consist of mere bone fragments.

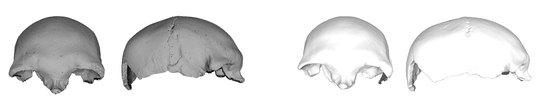

Figure 2: Left: Point cloud of a Brazilian skull obtained by the optical scanner (density: up to 300 points per mm^2). Right: Poisson reconstructed surface.

Case Study - Shape Model

The authors built an active shape model [2] based on the forensic database 3D-ID.org, and included 759 of the most complete skulls and 23 landmarks.

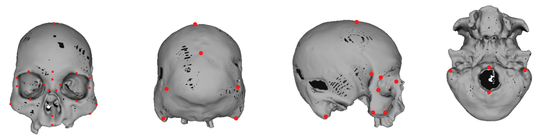

Figure 3: Placement of the anatomical landmarks

The 15 most complete Brazilian skulls are included in the shape model, and the landmarks were manually placed. Due to missing data, not every skull has all landmarks.

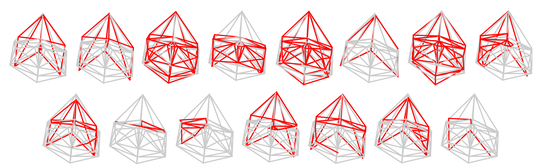

Figure 4: Landmarks (mesh vertices) of the 15 skulls from the Brazilian collection compared to the mean skull shape from the 3D-ID.org database.

The authors followed the conventional approach with aligning the shapes using Procrustes analysis (translation and rotation, but not size), and performed the PCA to identify the variation within the shapes.

Case Study - Shape Modeling Results

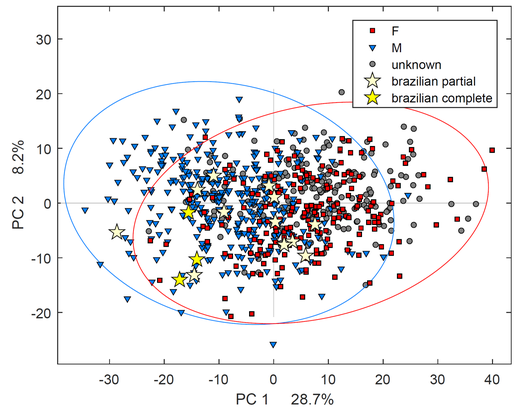

Figure 5: Gender on PC 1 vs. PC 2

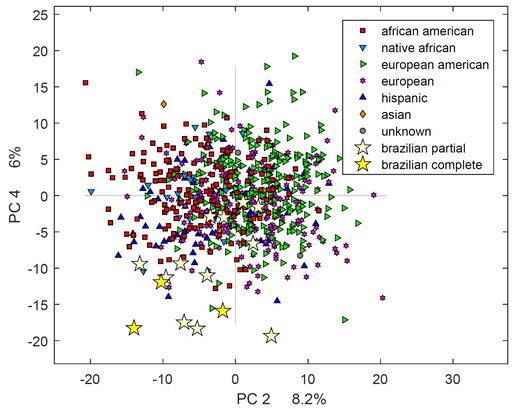

Figure 6: Origin on PC 2 vs. PC 4

The size of a skull is the largest contributor to shape variation, and explains nearly 30% of the total variation. Thus, the first principal component direction (PC 1) correlates highly to the gender distribution. The Brazilian skulls are not distinguishable from the general population.
The separation of the Brazilian skulls from the general population is most evident for PC 4 against PC 2. The three landmarks at the back of the skull contribute most to the fourth principal component. This indicates that the Brazilian skulls are distinguished from other considered populations by the shape of the posterior portion of the skull.

Planned Future Research - PhD of D. Messer

- **Automated registration of scans**
  So far, the process of scanning a single skull is a lot of manual work: A skull is placed in four different positions for scanning, and the resulting point clouds are assembled using the ICP algorithm implemented in the MeshLab tool. We are planning to automate this registration process.
- **Point-to-point registration and partial data**
  Instead of using manually annotated landmarks, we are aiming at using the full 360° point cloud. This would provide more information, but requires a correspondence between the different skulls. One of the challenges is that ancient skulls are incomplete. We plan to reconstruct the missing parts by incorporating specific shape priors in a statistical 3D model of a human skull.
- **Scanning more collections**
  We are planning to scan a collection of horse teeth, and of polar bear skulls in collaboration with the Natural History Museum of Denmark. We will not only document and visualize our cultural heritage, but potentially reveal new discoveries within evolutionary biology.

References

[1] E. R. Eiríksson, J. Wilm, D. B. Pedersen, and H. Aanæs. Precision and Accuracy Parameters in Structured Light 3-D Scanning. *ISPRS*, 2016.

[2] T. Cootes, E. Baldock, and J. Graham. An Introduction to Active Shape Models. *Image processing and analysis*, pages 223–248, 2000.