Detection of infant's cranial deformation based on spherical harmonics 3D modeling

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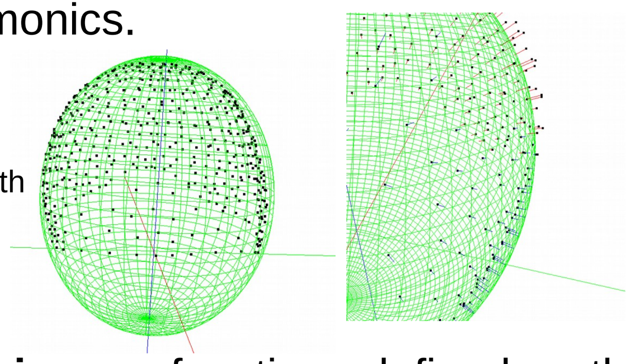
Abstract

An approach is presented to model the distances of an infant's cranium to a fitted ellipsoid with spherical harmonics. An automatic workflow is implemented which calculates the orthogonal distances from the surface of the cranium to the fitted triaxial ellipsoid and performs a spherical harmonic expansion. Based on this, the shape of the cranium can be approximated well with a linear combination of the first few spherical harmonic degrees. Furthermore, the coefficient which is assigned to the spherical harmonic of degree 2 and order -2 is identified as a possible indicator for plagiocephaly in infant's craniums. The developed workflow can be used in automatic classification tasks for the detection of cranial deformations in the future.

Introduction

Cranial deformation is an often occurring medical condition among infants. Recent research focuses on the use of photogrammetric 3D models as a more objective way of assessing the deformation. Barbero-García et al. (2017) suggested that cranial deformation can be assessed by the mean distance between the actual cranial shape and a fitted triaxial ellipsoid, as this ellipsoid represents the ideal head shape. However, it is expected that by analyzing the distances to the ellipsoid locally further information can be extracted, which might serve to detect the specific type of cranial deformation. In order to analyze the local variations of the distances to the ellipsoid, they are modeled with spherical harmonics.

Fitted ellipsoid with distances:



Spherical harmonics are functions defined on the surface of the sphere. Any function on a spherical surface can be approximated with a linear combination of weighted spherical harmonics, where the weights are represented by the spherical harmonic coefficients :

$$SH(\theta,\phi,l_{max}) = \sum_{l=0}^{\infty}\sum_{m=-l}^{l} f_l^m Y_l^m(\theta,\phi)$$

By modeling the distances of the cranium to its fitted ellipsoid those spherical harmonics which represent well the local variation of the distances are assigned a higher weight. This higher weight could thus serve as an indicator for the type of cranial deformation.

Methodology

A workflow was created to model the distances of a cranium to its best fitted ellipsoid with spherical harmonics. The workflow consists of the following steps:

1) Calculation of the best fitted ellipsoid

2) Estimation of the orthogonal distances from the cranial surface to that ellipsoid

3) Conversion to spherical coordinates of the closest points on the surface of the ellipsoid

4) Least squares fitting of the coefficients to model the distances with a defined maximum spherical harmonic degree $l_{max.}$

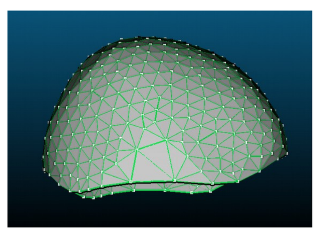
The calculation was performed for all 22 available cranial 3D models with increasing l_{max} values. The error of the resulting approximation of the cranium was calculated as the distance to the original cranial 3D model. Then, the resulting spherical harmonic coefficients were analyzed in order to find indicators for the occurring type of cranial deformation.

Used tools:

The automatic workflow was fully implemented in the Python programming language. For the fitting of the spherical harmonic coefficients the *shtools* library created by Wieczorek & Meschede (2018) was used.

Data sample:

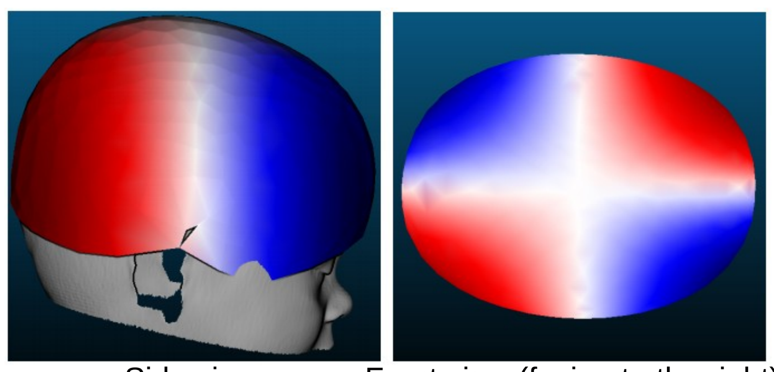
22 3D models of infant's craniums were available. The models originate from low-cost photogrammetric scans and have an accuracy of 2.1 mm. The craniums are classified as:



3D triangulated mesh representing a cranium

Number of craniums	Deformation type
1	Brachycephaly
1	Brachycephaly + Plagiocephaly
4	Plagiocephaly
4	Scaphocephaly
2	Trigonocephaly
10	No deformation

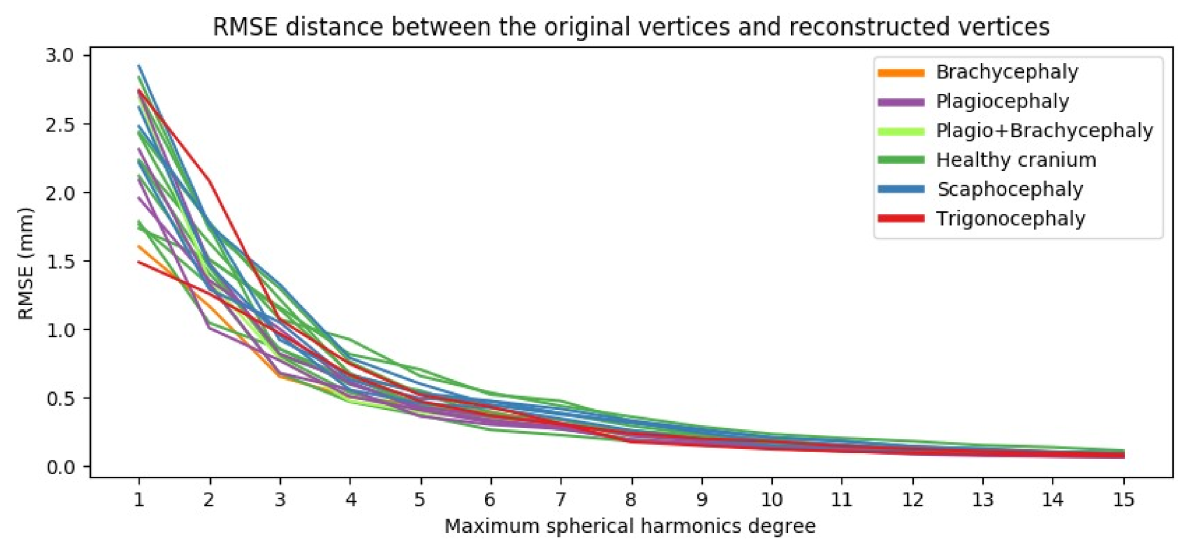
Visualization of the spherical harmonic of degree $l=2$ and order $m=-2$, mapped to the cranium:

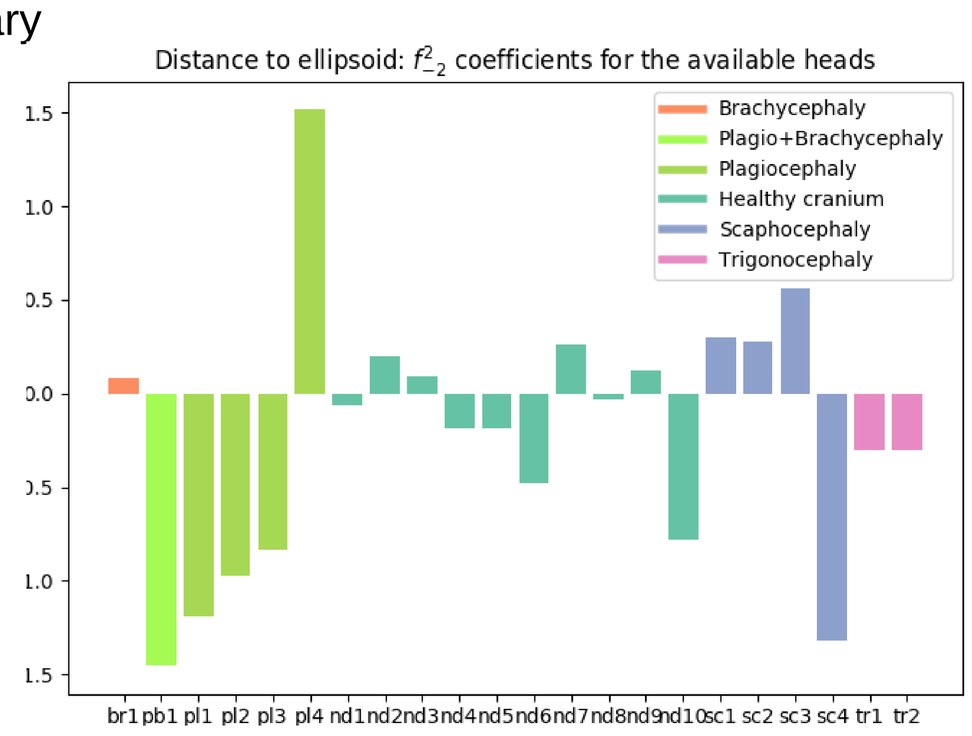


Side view   Front view (facing to the right)

Results & Discussion

- It could be shown that the distances to the ellipsoid can be approximated accurately with only low l_{max} values (e.g., an error of < 1 mm for all craniums at $l_{max} = 4$)
- The error converges towards zero with increasing l_{max} values → One cranium with trigonocephaly has a higher error at $l_{max} = 2$ → spherical harmonics of degree 3 are necessary to represent the shape of the cranium well





- In the created model, the coefficient for the spherical harmonic of degree $l=2$ and order $m=-2$ was assigned considerably higher/ lower values for craniums with plagiocephaly than for other craniums → it represents well asymmetry in the dorsal part of the cranium → possible indicator for plagiocephaly
- Spherical harmonic of degree $l=3$ and order $m=3$ possible indicator for trigonocephaly
- Only 22 cranial 3D models were available → results need to be verified with higher sample → then: establish classifiers which automatically detect plagiocephaly/ trigonocephaly in the cranium based on the value for these specific spherical harmonics

Objectives

- Create an automatic workflow which models the distances of an cranium to its best fitted ellipsoid with spherical harmonics
- Show that these distances can be approximated well with a low number of spherical harmonic degrees
- Find spherical harmonic coefficients which can serve as indicators for certain types of cranial deformation

Conclusions

- A highly weighted coefficient for the spherical harmonic of degree 2 and order -2 is an indicator for plagiocephaly.
- In the future an automatized tool for the detection of plagiocephaly can be developed
- For the other types of cranial deformation no clear indicators were found.
- The results need to be verified by repeating with a larger data sample

Selected literature

Barbero-García, I., Lerma, J. L., Marqués-Mateu, Á., & Miranda, P. (2017). Low-cost smartphone-based photogrammetry for the analysis of cranial deformation in infants. World neurosurgery, 102, 545-554.

Ducroz, C., Olivo-Marin, J. C., & Dufour, A. (2012, May). Characterization of cell shape and deformation in 3d using spherical harmonics. In 2012 9th IEEE International Symposium on Biomedical Imaging (ISBI) (pp. 848-851). IEEE.

Wieczorek, M. A., & Meschede, M. (2018). Shtools: Tools for working with spherical harmonics. Geochemistry, Geophysics, Geosystems, 19(8), 2574-2592.

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ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA GEODÉSICA CARTOGRÁFICA Y TOPOGRÁFICA

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