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Assessment of Registration Methods for Cranial 3D Modelling †

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Abstract: Three-dimensional (3D) models are a useful tool for cranial deformation analysis in infants. The registration of the head 3D models to a known coordinate system is vital for the obtainment of parameters and indexes that quantify deformation. In this study, three registration methodologies have been tested based on the principal component analysis (PCA) without tie points, and PCA measuring manually two and three identified tie points. Results show that the approach using PCA plus three manually identified tie points provides enough accuracy for the given application.

Keywords: cranial deformation; craniosynostosis; photogrammetry; plagiocephaly; principal component analysis (PCA)

1. Introduction

Cranial deformation is a commonly attended problem at paediatric consultations [1,2]. Traditionally, the deformation assessment is carried out using manual methods, such as measurements taken with callipers and measuring tape. In some cases, radiological imaging (Computed Tomography or Magnetic Resonance Imaging) is also employed.

Nowadays, the use of 3D models for cranial deformation assessment is becoming more common, but the methodology still needs to be improved [3]. The authors have presented a low-cost, smartphone-based methodology for head 3D model creation [4] and its accuracy has been evaluated by comparison with radiological imaging [5]. Reading the previous work is highly recommended for a better understanding of the current manuscript.

The registration of the head 3D models coming from different devices and arbitrary 3D technologies to a common reference system is still a challenge. For the purpose of monitoring cranial deformation in infants, model registration is required in order to calculate deformation indexes and compare multitemporal models.

Most 3D model solutions (e.g., STARScanner, Orthomerica, Orlando, Florida, USA; 3DMD, Atlanta, Georgia, USA) cover the whole area of the head, including the face, and use craniometric and facial points to register the model [3]. These methodologies are costly so their use is not widespread as part of the clinical routine. In cases where bone information is acquired (radiological images), bone structures are used to identify craniometric points.

For the developed application, the area in the 3D model is given by the area covered by a fitted cap, so the face is not registered. The identification of landmarks on the model is almost impossible, hampering the registration.

The proposed solution includes the manual identification of tie points by the medical staff. The identified tie points are later used for automatic registration in combination with PCA. Two methodologies are tested, using two and three manually identified tie points. The results are also compared with registration using PCA only.

2. Materials and Methods

2.1. Data Acquisition

The head 3D model data acquisition consists of 3 steps: (i) Placing a fitted cap on the infant's head, (ii) Locating the required craniometric points using stickers and (iii) Recording a slow-motion video of the infant head using a smartphone.

The position of the cap can vary significantly every time it is placed on an infant head (it can be placed to cover a bigger part of the forehead and/or nape, or go lower at one side). The required craniometric points can also have small differences in location. To evaluate the effect of cap and tie point position changes on the registration, the cap and points were put on a static model a total of 6 times. For each position, two data acquisitions were carried out, resulting in 12 models.

The models were created using a smartphone camera and Agisoft PhotoScan as described by the authors in a previous paper [4].

2.2. Registration

The registration process was carried out for each model using three different methodologies: (i) PCA without tie points; (ii) PCA plus two tie points (glabella and opisthocranion); and (iii) PCA plus three tie points (glabella and both pre-auricular points).

2.2.1. PCA Plus Two Tie Points

The identified tie points were glabella and opisthocranion. After PCA, the model was translated, so the origin of the coordinate systems was the mid-point between both tie points. The model was later rotated to match glabella-opisthocranion line with the x-axis.

2.2.2. PCA Plus Three Tie Points

The identified tie points were glabella and both pre-auricular points. After PCA the model is rotated and translated so the plane given by the 3 tie points matches z = 0, the line given by pre-auricular points matches y-axis and the line given by glabella and the line given by pre-auricular points matches x-axis (Figure 1a,b).

2.3. Distance Calculation

The differences were calculated as distances between meshes (Figure 1). For each pair of meshes, a reference one was chosen. For each point in the reference mesh, the distance to the second mesh was computed along the direction defined by the reference point and the coordinate system origin. This methodology improves the Iterative Closest Point (ICP) algorithm and fits the normal direction avoiding texture influence. It also has a lower computational cost than any ICP approach [6].

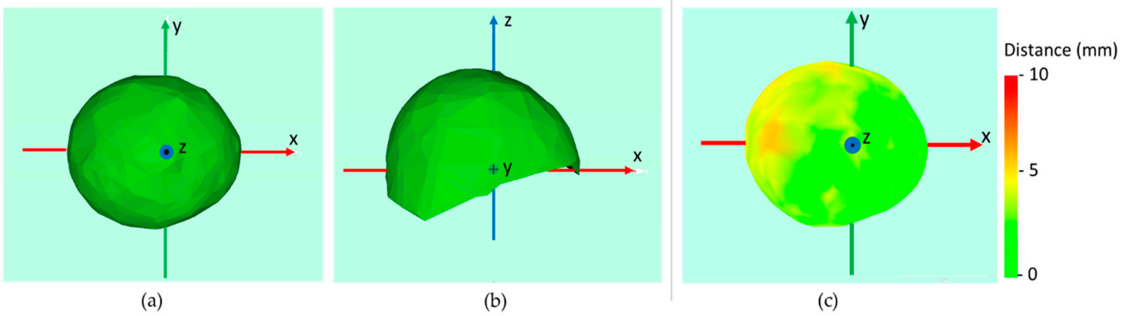

Figure 1. Top (**a**) and lateral (**b**) view of a model registered using CPA plus three tie points. Distances between two models (**c**).

3. Results

All the possible combinations between models were made for each methodology. The results are compared in general and for the same cap positions only (Table 1).

Table 1. Distances between registered models (mm).

	PCA without Tie Points		PCA Plus 2 Tie Points		PCA Plus 3 Tie Points	
Average distance	Mean	Std	Mean	Std	Mean	Std
All	4.6	3.1	3.4	2.0	1.9	1.1
Same position	0.7	0.6	1.6	0.9	1.5	0.7

PCA without tie points showed high errors for the whole set of 3D models but the results without varying the cap positioning are much better. As it was to be expected, the methodology is greatly affected by the position of the cap.

PCA plus two tie points moderately improved the results of the first method, although the results achieved under the same position increased the distances. The distance increment is explained partly by a model that presented high error for one of the identified points, causing the whole model to be badly registered.

PCA plus three tie points yielded the best results for the whole set of models, with distances below 2 mm. However, the distances for pairs of models taken without moving the cap were higher than those obtained using the PCA only.

4. Discussion

Accurate registration of the head 3D models is vital for the obtainment of useful information for cranial deformation assessment. This requirement becomes harder to achieve when the model does not include easily-identifiable points such as craniometric facial points or cranial information.

PCA was considered an interesting option as it easily identifies the maximum variance axis. However, it was pointed out that it is very dependent on the position of the cap and different examiners usually place the cap differently. To overcome this limitation a methodology has been developed based on the combination of PCA and tie points manually identified by the medical staff. The number of points must be limited so that it does not increase the data acquisition time. Furthermore, the required points must be easily identifiable in a moving infant.

Firstly, an approach based on only two tie points was tested. Opisthocranion and glabella were chosen, as they are important points for cranial deformation indexes. However, a problem found is the difficulty to identify opisthocranion reliably. A second approach replaced opisthocranion by the two pre-auricular points, left and right, which are easier to identify. Increasing the number of points to three allows defining a plane and therefore registering the model without the need for more data.

The results show that registration using PCA plus three tie points is independent of the cap position, so it is more applicable in real life.

The main disadvantage of the point-based registration is that the manually identified tie points are more subject to errors, as the registration is based on a very reduced number of points. This problem is worsened, as the points are located on the edge of the model, where more distortions are likely to happen. Nevertheless, promising results are expected after changing slightly the registration methodology.

5. Conclusions

A registration approach using PCA has been found to have enough accuracy for analysing cranial deformation. The method is useful as users are only required to identify three tie points (which can be stuck to the cap) and the registration can be fully automated. In the future, we are planning to slightly improve the presented registration methodology. Eventually, the methodology will be tested under real clinical conditions.

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