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# Analysis of 3D triangulated models of Madygenerpeton pustulatum fossil skull

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**Abstract**
In the paper, digital models of a fossil tetrapod skull, obtained by various 3D scanning methods, have been investigated by means of digital metrology. The unique skull of *Madygenerpeton pustulatum* was selected as example because it is of high interest for the palaeontological community as well as its characteristic surface covered by minute tubercles, thus challenging for digitization. Using the CAD software Geomagic Studio and Autodesk PowerShape, triangulated models generated with the devices AICON SmartScan, Mitutoyo AR Crysta and AR Strato, Artec Space Spider, CREAFORM GoScan, CREAFORM HandyScan and EinScan Pro have been compared with each other in couples. The geometrically and dimensionally closest-fitting models underwent detailed statistical analysis between surface polygons. Rating of the 3D triangulated models was done. Three of them exhibited differences $\Delta_d$ below 0.1 mm, which can be considered highly satisfactory for the smallest tubercles of ca. 0.7 mm diameter.

Keywords: *Madygenerpeton*, Additive Manufacturing, triangular model, polygonal analysis, accuracy

## 1. Introduction

Fossil remains of ancient organisms are unique documents of life in the geological past. Their individual appearance is determined by biological characteristics but also by the geological processes related to fossilization, resulting in different preservational patterns. Fossils are often fragile and can be easily damaged during transportation or reproduction.

Non-destructive or even non-contact digital methods offer various advanatges for providing access to fossils for several groups of users (researchers, students, museum visitors, broader public). Digital models can be viewed, manipulated on screen or used for obtaining analogue (printed) copies simultaneously and without touching the actual object.

Although digital representation increasingly becomes standard in palaeontology [1], no quantitative studies evaluating digital models of fossils have been published so far. The novel aspect of our contribution is an attempt to fill in this gap using digital metrology and to provide a method for further objective evaluations in terms of required reproduction accuracy.

## 2. Description of the object

We obtained and evaluated several digital models of the holotype specimen of *Madygenerpeton pustulatum* [2], a detached and somewhat deformed skull of a 'reptiliomorph amphibian' from the Triassic of Kyrgyzstan. The skull is lacking the lower jaw. Besides interest in the type and only specimen of a *Madygenerpeton* skull for exhibitions and research purposes, its challenging morphology characterized by numerous minute tubercles covering the surface of the bone makes it an object valuable for digital reproduction. The object is shown in Figure 1.

The analyzed 3D models have been generated using photogrammetry, handheld structured light scanning, laser scanning, industrial structured light scanning, coordinate measuring machines and computer microtomography (µCT). Here, we compare triangulated 3D models obtained from AICON SmartScan, Mitutoyo AR Crysta and AR Strato, Artec Space Spider, CREAFORM GoScan, CREAFORM HandyScan and EinScan Pro devices. Additonally, physical copies have been produced by various additive manufacturing methods based on the Artec-derived 3D model [3].

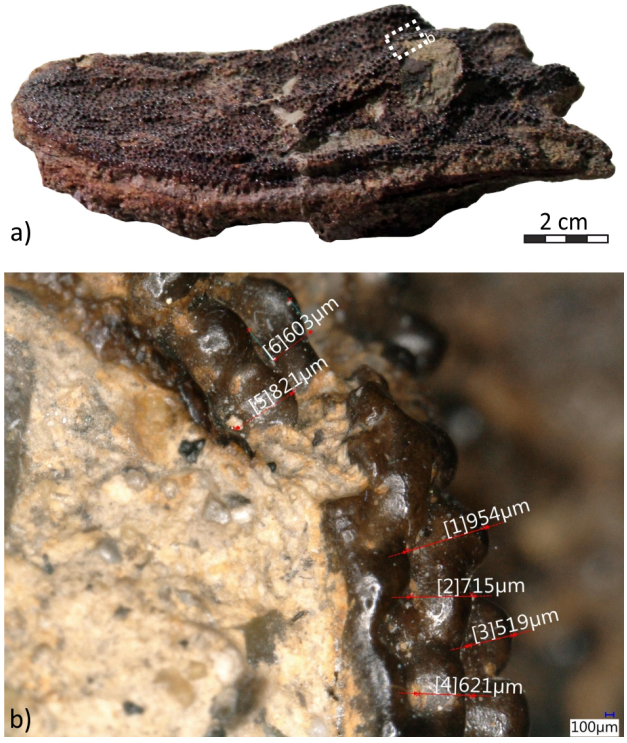


**Figure 1.** Skull of *Madygenerpeton pustulatum* (holotype FG 596/V/4, housed at the TU Bergakademie Freiberg): **a)** general view, and **b)** close-up picture of bony tubercles covering the skull in the region of left orbit

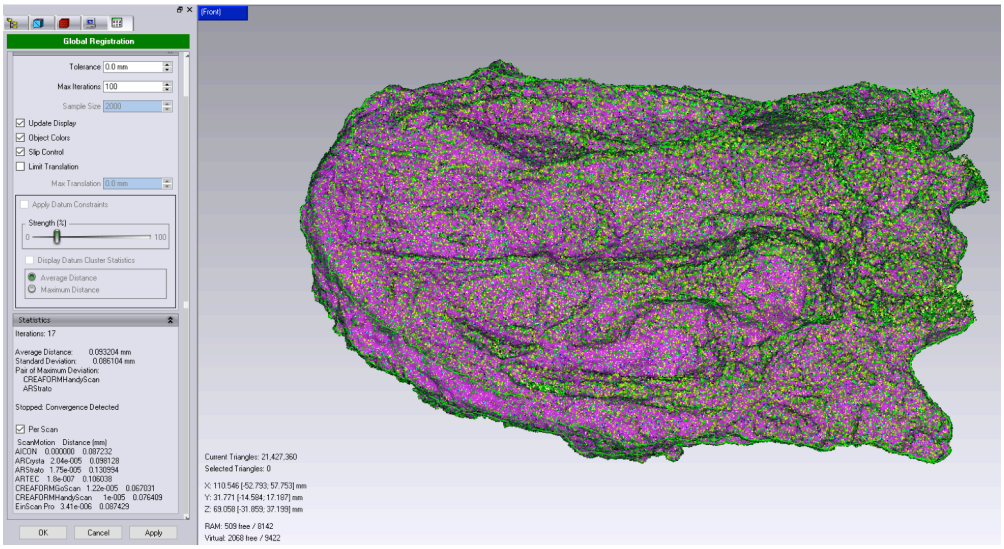


**Figure 2.** Automatic superposition of tested 3D models from 2000 measurements

**Table 1** Example of the obtained distances between surfaces represented by different models

| Reference model | Test model | Distance statistics | | | | | |
|---|---|---|---|---|---|---|---|
| | | Maximal $\Delta_d$ | | Average $\overline{\Delta_d}$ | | | Standard deviation $\sigma\{\Delta_d\}$ |
| | | positive | negative | all | positive | negative | |
| AICON | AR Crysta | 0.652 | -2.823 | 0.101 | 0.126 | -0.054 | 0.095 |
| AICON | AR Strato | 0.686 | -4.502 | 0.119 | 0.128 | -0.051 | 0.080 |

## 3. Comparative analysis

A comparative analysis was performed in two stages. First, coupled 3D models underwent visual and statistical analysis of the differences between them. Next, the closest fitting models, geometrically and dimensionally, were chosen. These models underwent detailed statistical analysis between surface polygons. In the experiments, CAD software Geomagic Studio and Autodesk PowerShape was used.

Due to the uniquenness of the analysed object, no reference model was available. Thus, each couple of models underwent comparison between one another based on the distance $\Delta_d$ between polygons. Figure 2 shows an example of comparison of two digital models, and Table 1 contains the results for AICON model compared with AR Crysta and AR Strato.

The most informative parameter appeared to be average distance $\overline{\Delta_d}$ and its standard deviation $\sigma\{\Delta_d\}$. Especially the latter one is a good measure for the difference between the tested 3D models. Figure 3 represents graphically the rating of the digital 3D models provided by the respective devices. The doubled blue lines corrspond with close results, while the red lines show the couples where the models differed substantially. Three of the analysed models exhibited differences $\Delta_d$ below 0.1 mm, which can be considered highly satisfactory, since the smallest tubercles on the surface of the scanned skull were of ca. 0.7 mm diameter. Others had $\Delta_d$ up to 0.5 mm, so that accuracy of these models was insufficient.

## 4. Conclusions

The performed comparative statistical analysis enabled assessment of technical abilities of the scanning devices and respective 3D models of the fossil skull of *Madygenerpeton*. The objectives were focused on the correctness of the further fabrication of its copy with the Additive Manufacturing technology.

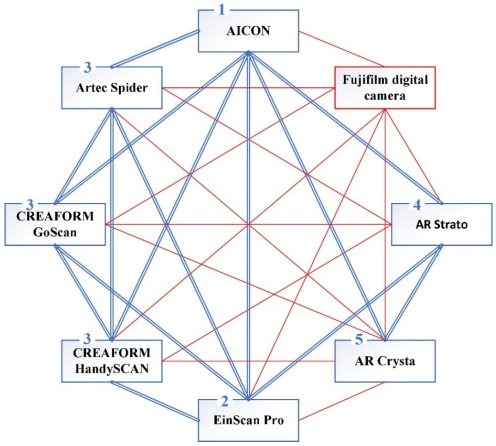


**Figure 3.** Rating of the devices based on the smallest distances $\Delta_d$ between the respective 3D models obtained from scanning

Due to the object's uniqueness, no reference model was available. As a result of the analysis of distances between 3D surfaces of each couple, the models with small differences related to the demanded reproduction accuracy were chosen. It allowed to avoid the unnecessary expenses in the subsequent AM process of 3D printing of the copies of this fossil object.

## References


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