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Analysis of the fidelity of the Computed Tomography 3D triangulated model of Madygenerpeton pustulatum fossil skull

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Abstract

The quality of digital 3D reproductions of fossils can be assessed by quantifying model fidelity, which, however, has rarely been attempted for fossils. In the present study, a tomographic 3D model of the skull of *Madygenerpeton pustulatum*, a reptiliomorph amphibian from the Triassic (ca. 237 million years before present) of Madygen in Kyrgyzstan (Central Asia) was obtained. Comparative accuracy analysis was performed using triangulated models from the different surface-scanning systems as a reference. Accuracy was represented by the distances Δ_d between the points in each couple of models, average distance and the square root distance. Notably, the smallest distances were between the YXLON CT model and AICON SmartScan model with average $\overline{\Delta_d}$ = 18 µm, close to the nominal length measuring error of AICON. Compared to other scanned 3D models, average distances were always below 0.1 mm with standard deviations $\sigma\{\Delta_d\}$ below 0.2 mm. Thus, it was demonstrated that the accuracy of triangulated model obtained from CT exhibited satisfactory accuracy for further AM processing

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

1. Introduction

There is range of possibilities for visualizing and replicating of unique fossils, to make them available for investigations and wider public. Recent development of digital methods of surface and tomographic 3D scanning enabled virtual representation and 3D printing of the fossil objects and sharing of virtual fossil specimens [1]. This opens up a large field of applications, such as creation of photorealistic 3D models for teaching purposes or virtual exhibits, making possible remote collaboration on specimens, digital restoration, anatomical studies, functional modelling, and fabrication of multiple copies. Moreover, digital methods of investigation and reproduction have important advantage involving only little physical contact. They are genuinely non-destructive, reducing the risk of damaging the precious specimens to unlikely accidents during transport, or through manipulation during digitization process.

Computed microtomography (µCT) increasingly becomes a standard technique for investigating fossils [2], especially cranial remains of fossil vertebrates [3]. The tomographic method allows for non-destructive studies of internal structures of a fossil specimen, but also for visualizing features situated on its surface but covered by sediment that cannot be removed without the risk of damaging the fossil. External geometries obtained from computed tomography can be used for creating 3D surface models, readily available for countless applications such as digital visualization, non-contact manipulation of the digital specimen, remote cooperation, or replication by means of additive manufacturing [4]. Unlike optical scanning, each data point within computer tomography (CT) imagery is a function of X-ray attenuation, where unexpected change in relative density value can result from the finite boundary of a volume element overlaying two or more materials [5].

The quality of digital 3D reproductions of fossils can be assessed by quantifying model fidelity [6], which, however, has rarely been attempted for fossils. In the present study, a tomographic 3D model of the skull of *Madygenerpeton pustulatum*, a reptiliomorph amphibian from the Triassic (ca. 237 million years before present) of Madygen in Kyrgyzstan (Central Asia) was obtained. Sediment has been removed digitally from the tomographic model based on the density contrast, but evaluation of the reproduction fidelity became difficult due to the lack of the reference surface and dimensions. Figure 1 presents the overall veiw of the fossil skull, and Figure 2 shows a section of tomography revealing the teeth hidden in sediment.

Figure 1. Fossil skull of *Madygenerpeton pustulatum*

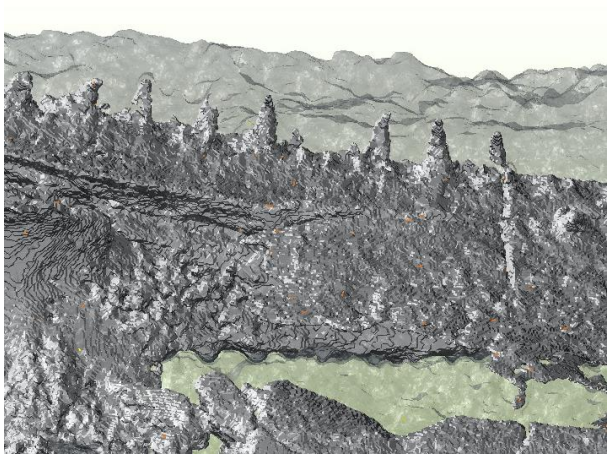

Figure 2. Details of the fossil skull (darker fields) hidden in sedimentary rock (greenish gray fields)

2. Materials and methods

The sediment is covering structures from the underside of the specimen. Especially, parts of the dentition are hidden by sedimentary rocks, which cannot be removed due to the high risk of fossil breakage. Computed microtomography represents excellent solution, providing the possibility to differentiate between bone and sediment. Digital images can be processed manually, but when the density contrast is sufficient, differentitaion can be made automatically. However, in the case of comparative analysis, it is necessary to use the whole-surface scanned model obtained from µCT device. For the current research, the model has been obtained from a custom-built YXLON µCT scanner at the Museum für Naturkunde Berlin. This model was further compared with several surface models obtained from different 3D scanning devices. For the comparative analysis, following devices were used [7]:

- AICON SmartScan: Length measuring error 20 µm
- AR Crysta: $MPE_E = 1.7 + 3L/1000$ µm
- ARStrato: $MPE_E = 0.7 + 2.5L/1000$ µm
- ARTEC: accuracy of 3D point 50 µm
- Creaform GoScan: $MPE_E = 0.05 + L/6600$ mm
- Creaform HandyScan: $MPE_E = 0.02 + L/16{,}600$ mm
- EinScan Pro: automatic and manual mode, accuracy 0.05 mm

Comparative accuracy analysis was performed using triangulated models from the different surface-scanning systems as a reference. In fact, it was necessary to analyse each couple twice, taking as a reference alternately each of the models. Accuracy was represented by the distances Δ_d between the points in each couple of models, average distance and the square root distance.

3. Results

Calculations of the reference model were made in two directions: outwards (positive distance), and inwards (negative distance). Table 1 presents the results of statistical analysis of the distances Δ_d between two models, AICON and YXLON µCT, showing maximal values, averages in both directions, and standard deviations. Due to peculiarities of each scanning technology, number and geometry of the polygons in each model is different. Thus, the distances between models always depend on which one is taken as a reference. Notably, The distances from µCT model were the largest for each reference. Figure 3 demonstrates example of the calculated distances between AICON as a reference and each other model.

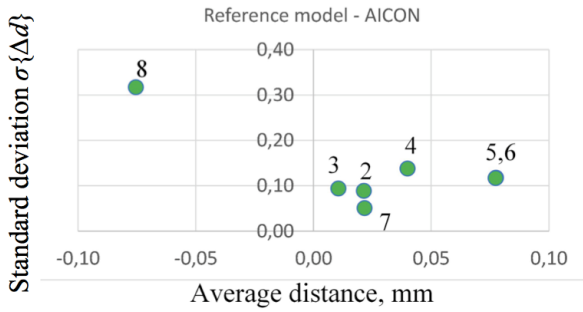

Figure 3. Statistics of distances between AICON taken as a reference and each other analyzed model (1 – AICON; 2 – AR Crysta; 3 – AR Strato; 4 – ARTEC; 5 – CREAFORM GoScan; 6 – CREAFORM HandyScan; 7 – EinScan Pro; 8 – Yxlon µCT)

The smallest distances were found between the YXLON µCT model and AICON SmartScan model. The average value $\overline{\Delta_d}$ = 18 µm was close to the nominal length measuring error of AICON scanner, which means very small distortion of the object's geometry, at the level of measuring capability of the device. Compared to other scanned 3D models, average distances were always below 0.1 mm with standard deviations $\sigma\{\Delta_d\}$ below 0.2 mm.

4. Conclusions

Comparative analysis of the distances between polygonal models revealed that the computer tomography model differed the most from all other ones. This can be attributed to the fact that the scanning principles here were different from other methods. It was demonstrated, however, that the accuracy of triangulated model obtained from CT exhibited satisfactory accuracy for further AM processing.

References

[1] Collins PC, Martill DM, Smyth RSH, Byrne R and Simms MJ 2021 *Proceedings of the Geologists' Association* **132**(6) 780-3

[2] de Carvalho MGP, Maisey JG, Mendes ID and de Souza Carvalho I 2022 *Cretaceous Research* 105454 Paper in Press

[3] Kundrát M, Coria RA, Manning TW, Snitting D, Chiappe LM, Nudds J and Ahlberg PE 2020 *Current Biology* **30(21)** 4263-4269.e2

[4] Mitsopoulou V, Michailidis D, Theodorou E, Isidorou S, Roussiakis S, Vasilopoulos T, Polydoras S, Kaisarlis G, Spitas V, Stathopoulou E, Provatidis C, Theodorou G 2015 *Quaternary International* **379** 4-13

[5] Elliot TR, Heck RJ 2007 Geoderma **141**(1–2) 60-70.

[6] Furtner MJ and Brophy JK 2023 *Journal of Archaeological Science: Reports* **47** 103762

[7] Garashchenko Y, Kogan I and Rucki M 2022 *Metrology and Measurement Systems* **29(1)** 37-51

Table 1 Results of initial statistical analysis of the distances between two 3D models, AICON and YXLON µCT

Reference model	Test model	Distance statistics					
		maximum		average $\overline{\Delta_d}$			standard deviation $\sigma\{\Delta_d\}$
		positive	negative	all	positive	negative	
AICON	YXLON µCT	1.9986	-1.9999	-0.0754	0.0652	-0.1698	0.3172
YXLON µCT	AICON	0.9459	-1.2649	-0.0183	0.0638	-0.0454	0.0778