

3D Scanning Guidelines for Skeletal Remains with Artec Studio 11 at the University of Sheffield

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Guidelines

The present guidelines were created with Artec Spider and Eva scanners along with Artec Studio 11 from Artec 3D which were acquired by the Department of Archaeology at the University of Sheffield (UK). During the author's learning process, an initial simplified version of the present guidelines was created with the aim of being used by departmental staff and students. However, a more extensive version was later created as a resource for scanning bones with Artec 3D scanners or for those with thoughts of acquiring this equipment for bone scans. The technical steps of these guidelines do not substitute for the user guide of Artec Studio 11 from Artec 3D. Reading of the Artec Studio 11 User Guide is highly recommended before one starts to scan. For those doing research with skeletal remains, these guidelines serve to complement the User Guide Artec Studio 11. They were written to reflect the author's experience with Artec Spider and Eva scanners. The reader may want to explore options offered by Artec Studio 11 which are not mentioned in the present guidelines. The guidelines are as follows:

1. Allow the Artec Spider scanner to quickly warm up in the preview mode for optimum bone scanning (Fig. 1). To select the preview mode, select the scan button located in the left menu bar. You can also select the preview mode directly on the scanner by pushing the button up one time (User Guide Artec Studio 11: 37). Warming up is not required for the Artec Eva scanner.

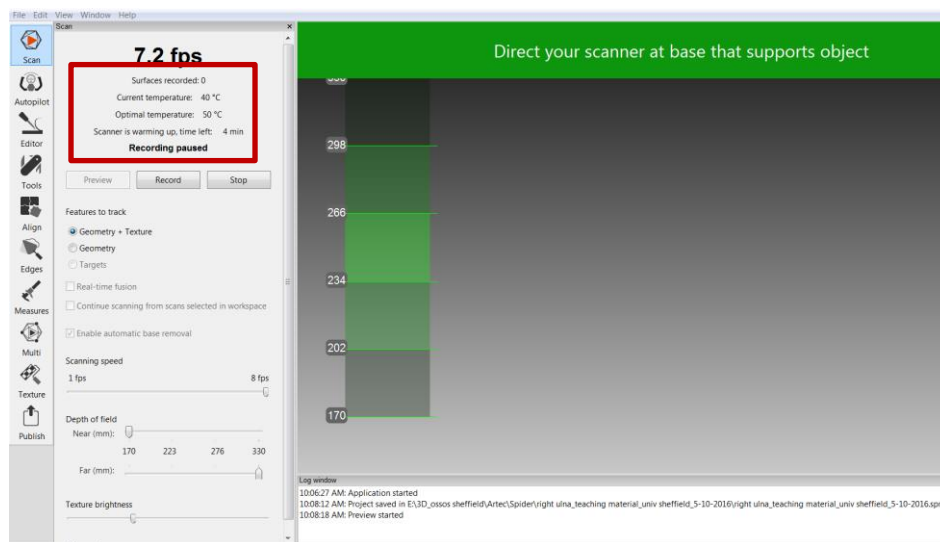


Figure 1. Temperature and warming up time (in red) for Artec Spider scanner.

2. Calibrate the Artec Spider scanner once every week. Remember to register the calibration on to a calibration log. Instructions are located in the user guide (User Guide Artec Studio 11: 161 – 168). Please note that the base of the calibration table should be aligned with the lines on the paper.

Artec Eva is pre-calibrated. If it suffers damage due to a fall, it may affect its pre-calibration values. In case of damage, the calibration may have to be corrected to its original values (User Guide Artec Studio 11: 157-161).

3. It is suggested to scan with zero sensitivity. Scanning whitish bones and teeth (shining surfaces) are cases of exception which may require an increase in sensitivity levels. In preview mode, you can set up the sensitivity level (20% to 30% - User Guide Artec Studio 11: 51- 53). It may be easier to scan a bone without the scanner losing track by increasing sensitivity. Avoid setting higher sensitivity values as the scan may result in duplicate images of the bone surface.

Whitish bones seem to be difficult to scan and may result in surface and/or texture error, such as the capture of shadows on the 3D model. It is recommended to perform scanning in a dark environment; close the curtains and turn off the lights. Use a textured base like a piece of paper with drawings on it and, if necessary, slightly increase scanning sensitivity. In addition, reduce texture brightness or set it to zero when scanning.

Artec Eva seems better suited to scan shining surfaces than Artec Spider. Scanning errors have been encountered while using Artec Spider in capturing teeth with a very whitish shining surface. For example, when scanning a Baboon's maxillary canines with a shining surface due to severe dental wear, an error was encountered on the final 3D digital model showing an incorrect alignment between scans of the canines. In contrast, these same Baboon's canines were successfully captured with Artec Eva with the same settings as Artec Spider. Although the application of anti-glare spray results in a clear and highly accurate scan with Artec Spider, its use is not advisable on bones and teeth, since it may damage them and leave residues. Scanning of


shiny surfaces and thin edges are successfully improved by holding the scanner at a 90-degree angle to the base with cameras directed to the bone, increasing the scanner sensitivity and reducing the texture brightness to zero.

4. Maintain the other scan options with their original setting values (User Guide Artec Studio 11: 51-55, 147-151 and 153-154). Select geometry + texture to create a 3D digital model with texture/colour in the scan function. The geometry option alone will create a monochromatic model. If scanning and/or texture errors emerge on the final 3D digital model, evaluate these settings to determine if they will resolve the errors while creating a new 3D digital model of the same bone.

5. Have the base removal option enabled in the scan options (User Guide Artec Studio 11: 43). Base recognition will lead to the appearance of grey squares grid on the screen. The scanners can recognize the table surface and a piece of textured paper (avoid simple texture as lines) as a base, but will fail to recognize foam and a rotary table as a base (no grey grid appear on screen) but will instead recognize it as an object. Base removal will automatically be performed when leaving the scan function.

6. In preview mode, direct the scanner to the bone to identify possible areas that may be difficult to scan to plan out how you can proceed with scanning. Always keep your eyes on the computer screen in order to see what the cameras are capturing and not what you see.

7. In the left menu, avoid using the autopilot option or the real-time fusion in the scan options. Manually perform the alignment and post processing of the captured scans. This allows for better user control in the creation of a 3D digital model of a bone for research purposes.

8. To scan, either push the button up a second time in Artec Spider, select  in Artec Eva, or click record on the software (Fig. 2, User Guide Artec Studio 11: 38-43). Remember to direct the scanner base (where the cameras are located) towards the bone for scanning. Scanning with Artec scanners can be done either by moving the scanner along the bone or fixing the scanner while moving the bone with a rotary table.

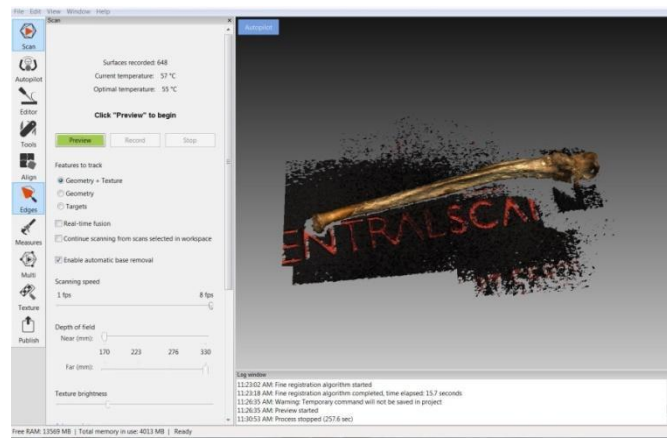


Figure 2. One scan of a right human ulna with noise (foam in the bottom recognized as an object by Artec Spider).

Quicker scanning of larger bones can be obtained with Artec Eva, while Artec Spider scans smaller bones with a higher level of detail. Both scanners can be used in the same project. Use Artec Eva to capture the overall geometry of a bone, such as a cranium. Implement Artec Spider for cranial features with greater detail like the nasal cavity, which Artec Eva cannot capture. The use of Artec Spider to scan a large bone may not be effective, because it will lead to a heavier model which computers cannot process. Excessively heavier model mesh will have to be simplified leading to the loss of triangulated data points. Decide which scanner to use according to your aims and objectives.

Bones with regular morphology, such as a rib's shaft, may be more difficult to align and create a 3D digital model without targets. Artec 3D recommends using targets when scanning (see instructions at <https://artecgroup.zendesk.com/hc/en-us/articles/204851221-Scanning-with-photogrammetry->). A bone that already has pencil or pen markings, such as collection numbers, may help in the alignment. However, writing new marks on bones is not appropriate for ethical and curatorial reasons, regardless of whether you erase the pencil marks at the end. The use of targets on human bones should be agreed upon with collection curators, since targets consist of small stickers which are put on the surface. Although not a strong adhesive, targets can potentially damage poorly preserved skeletal remains.

When a bone, supported inside a sponge, is scanned in rotation, it can lead to the appearance of shadows on the final 3D digital textured model. To avoid the presence of shadows, consider eliminating triangulation points located close to the sponge in each captured scan.

9. To stop scanning, click stop on the software or push Artec Spider scanner button down. In Artec Eva, you can click the square button. In order to confirm that error was not captured on the scan, press the left mouse button and drag to rotate the scan. This will give you a point cloud. If two parallel point clouds exist, when there should only be one, it is an incorrect bone scan.

10. Editor options – eraser allows you to eliminate noise not associated with the bone scan (Fig. 3, User Guide

Artec Studio 11: 81-82, 85-90). When the editor option is selected, it does a fine registration (User Guide Artec Studio 11: 91-93). Lasso is an easy option to eliminate noise. Optional: In order to reduce the size of the noise in editor, use the tools in the following sequence: 1) cut off-plane plane selection (selecting 3 to 4 points in the extremities of the plane makes it easier to eliminate the base), 2) lasso selection, 3) 2D selection. Do not eliminate all small size noise, as it will be removed during the post process which removes outliers. This will diminish the time spent on the editor eraser option.

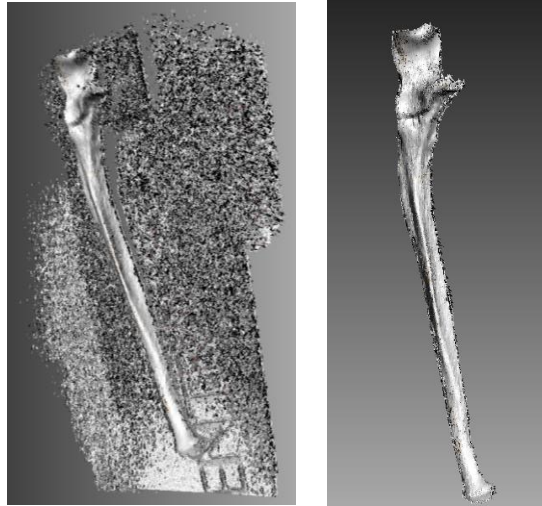


Figure 3. Scan of a right ulna before (left) and after (right) eliminating noise.

11. Each bone scan is composed of several frames (double click on a scan to open the information of the frames – Fig. 4). To return to the scans list, click on the red arrow. I would recommend eliminating frames with error of 0.3 or greater in Artec Spider and 0.6 or greater in Artec Eva in order to create an optimized 3D digital model. Higher values are suggested for Artec Eva due to its lower resolution in contrast to Artec Spider. By eliminating frames with error size equal to or superior to a value, a lower error results after conducting global registration.

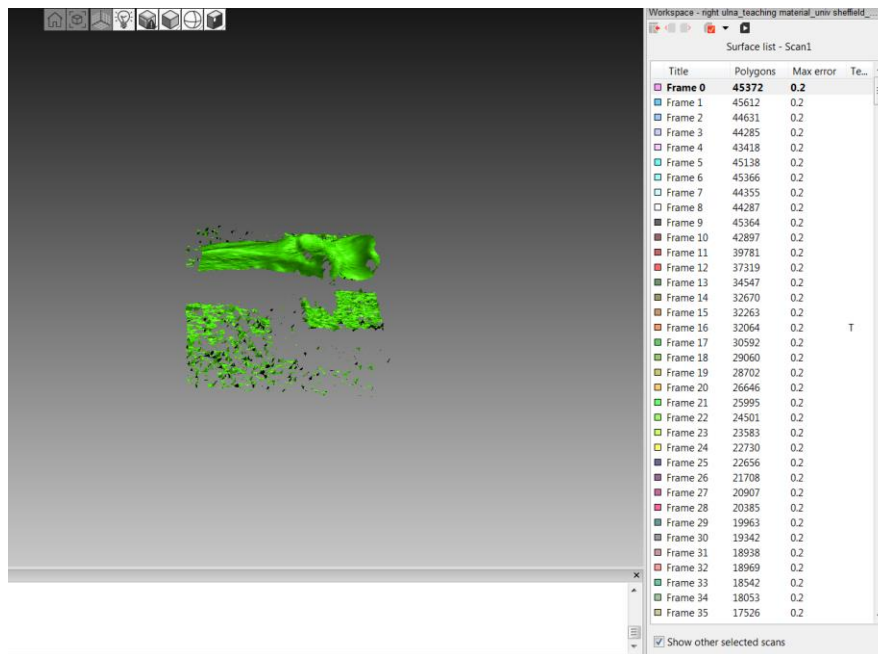


Figure 4. Frames within a scan.

12. Repeat steps 8 to 11 to scan the different bone surfaces and eliminate noise and error. In each scan some overlapping areas have to exist, so that alignment between them can occur. Please note that for scans to be visible and active, the eye symbol (right menu) has to be visible. If the square above the eye symbols is clicked, it allows for the appearance or disappearance of the eye symbols, and consequently for the appearance or disappearance of all scans.

13. Alignment between scans will put each captured scan in the correct position for the creation of a 3D digital model and not the fusion of scans forming the 3D model. Usually it is easier to align two or more bone scans (left menu) in a monochromatic colour rather than with texture (monochromatic option can be selected in the upper menu). Use texture option if it helps to align bone scans which present regular features, especially if a collection number is written in the bone surface or colour differences exists.

All bone scans have to be visible (the eye icon on the right menu has to be present) before conducting alignment. Avoid using the non-rigid option since it can make the alignment between points more variable; try to be as rigid as possible to potentially avoid a misalignment between scans. The first scan will always be depicted in purple (Fig. 5). If you have more than two aligned scans, select them on the left menu and click enter, which will also display them in purple. Click on the non-aligned scan which will illustrate it in green (Fig. 5). To rotate the recent bone scan, click ctrl + shift+ left button of the mouse. Proceed with the alignment by orientating the different bone scans in the same direction in order to put point pairs on common features shared on the bone scans (Fig. 6, 7). Alignments between scans with the pairs system functions well, but if possible, try to put common points at the extremities of each bone scan for an optimal alignment. Complex

alignment may be used when the operator is aligning more than two scans at the same time (Fig. 8).

Overlapping/dragging two scans or an auto-alignment for bone scans may also be implemented. It may not work between scans of bones with regular features because they do not have enough shape variability for logarithms to recognize common triangulated points between scans (User Guide Artec Studio 11: 93-105, 149-150). If this option fails, use the pairs system.

After alignment, by clicking on the left button of the mouse and dragging to rotate the bone scans, this will give you a points cloud. If two points clouds appear parallel, when there should just be one, it means it is misaligned. Alignment is not the final fusion between scans, so it is possible to re-align a scan that was previously misaligned. By clicking on the previously misaligned scan without clicking enter, it will get a green colour and it is possible to re-align it again. If it still does not align correctly, eliminate the bone scan and scan the missing area again.

After alignment, click apply, and select texture in the above menu.

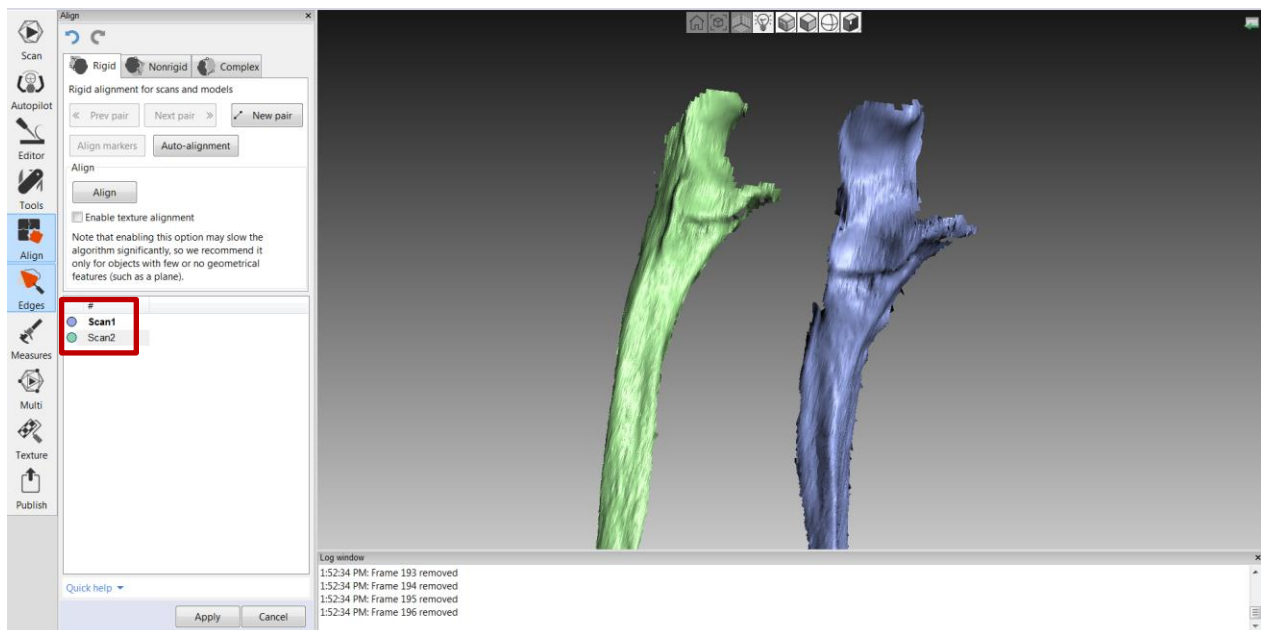


Figure 5. Two different scans of a right ulna with some overlapping area before alignment.

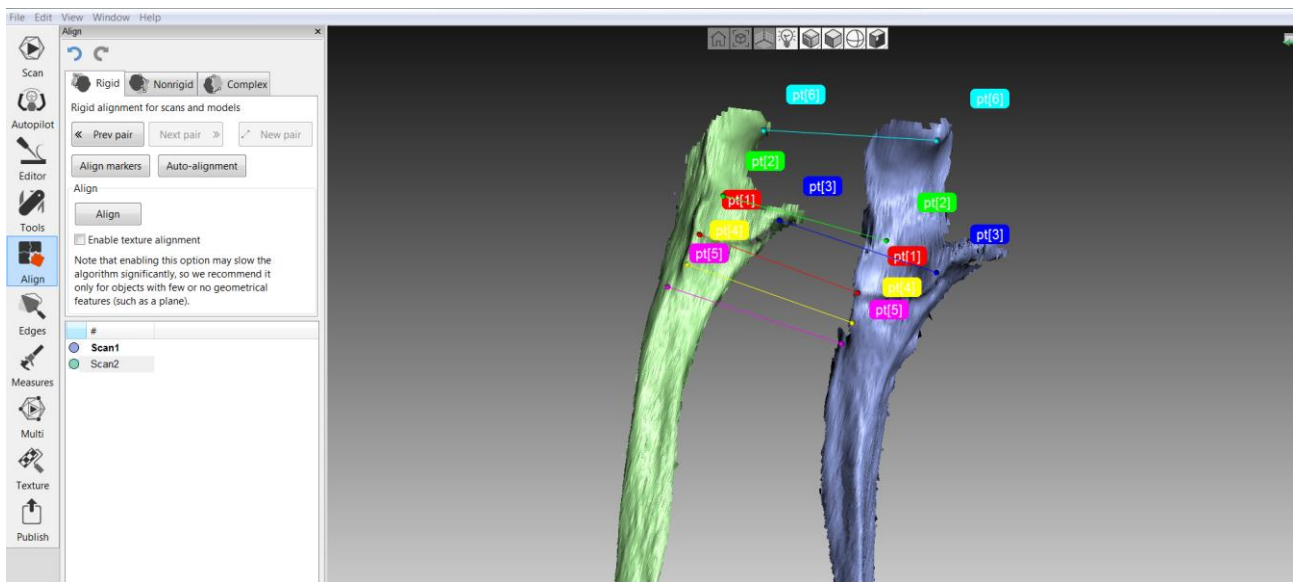


Figure 6. Pairs points in common features between scans for rigid alignment.

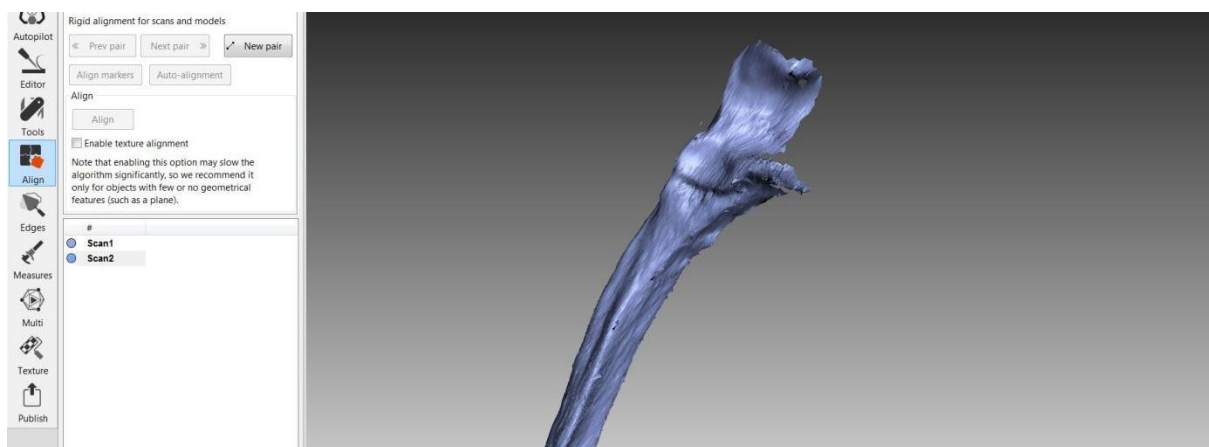


Figure 7. Two aligned scans.

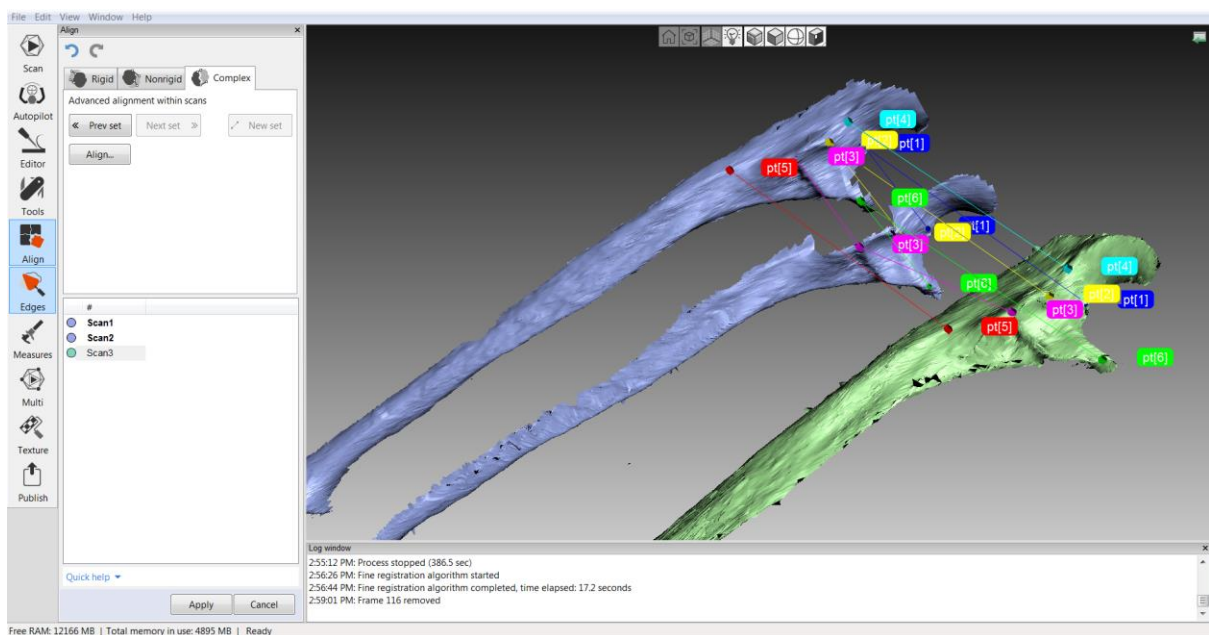


Figure 8. Complex alignment with pairs points between 3 scans.

Occasionally in the alignment function, only a reduced view of the bone scan appears. By going back to editor, the entire captured bone surface will be present. This reduced view of the scan can be explained by the software design to reduce the load on the graphics card (Fig. 9).

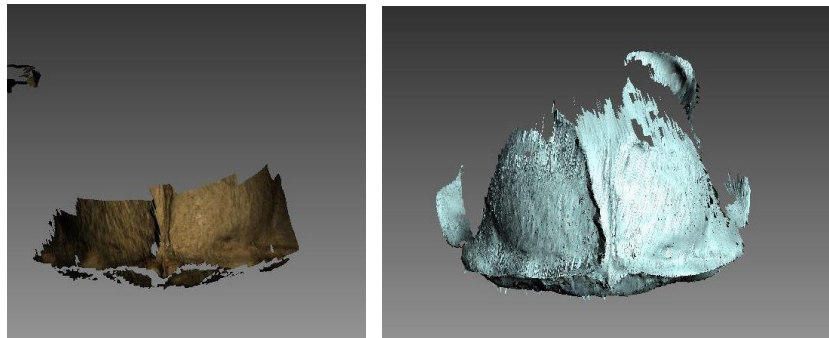


Figure 9. Exhibition of the same captured cranium scan in different function modes. Left: alignment function; right: editor mode.

14. Repeat the steps of scanning, noise elimination and alignment until all bone surfaces have been scanned. Small holes may be left at this point to avoid creating a much heavier model, which may be difficult to operate. However, scan the missing bone surface if large holes are still present. Artificial filling of larger holes may lead to an artificially smoothed surface or to the presence of ridges.

15. After all scans are aligned, click on tools (left menu) and do a global registration in manual mode (User Guide Artec Studio 11: 105-106). To save time in the post process, consider doing a global registration with the geometry option, not with the geometry and texture option.

After global registration, the quality of the bone scans can be accessed by looking at the maximum error value on the right column (Fig. 10, User Guide Artec Studio 11: 78 - 81). If the error is elevated or it indicates failed frames, go to frames section. Eliminate failed frames by clicking and deleting them with the keyboard. Eliminating frames can leave holes in scans, which require scanning the missing area once more. Additionally, delete frames with a high maximum error (e.g., with 0.3 or above for Artec Spider, and 0.6 or higher for Artec Eva). The quality of the 3D digital model should be accessed by determining the level of deviation between two models of the same bone created at different moments, and precision between measurements taken directly from the bone versus measurements on the 3D digital model.

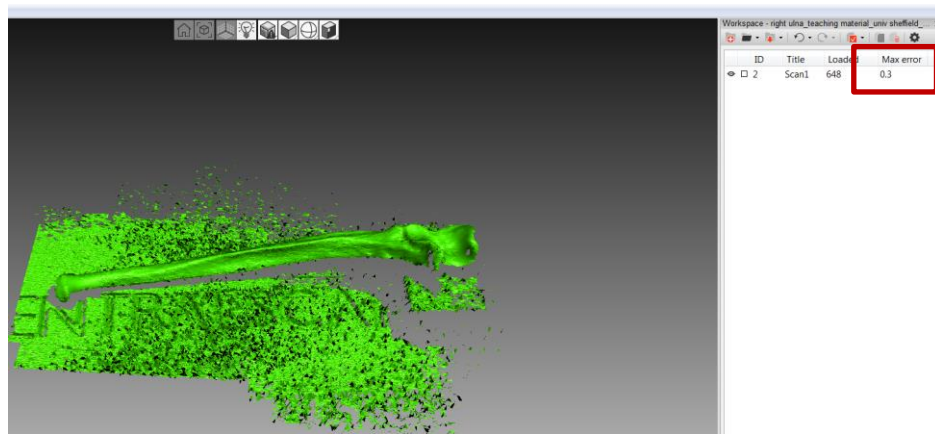


Figure 10. Maximum error in a scan.

16. Eliminate outliers (Fig. 11, User Guide Artec Studio 11: 105-106): The values of outliers may also be modified although increased values may affect the quality of the 3D digital model. To go back to the original setting values on tools menu, click on the arrow to visualize options, followed by a click on the blue square. Values will reset to its original settings and the square will become white again.



Figure 11. Aligned scans after removing outliers.

17. In tools, perform a sharp fusion of scans to create a 3D digital model of a bone, with a resolution of 0.1 mm for Artec Spider, and a resolution between 0.5 and 1 mm for Artec Eva. A lower resolution in Artec Eva may result in higher surface error, whereas a higher resolution may result in excessive surface smoothness resulting in the loss of some surface detail. Hence you need to determine what is best for the model in question. Remember that Artec Eva is best suited to capture larger bones like the cranium, but will have less detail than a 3D digital model captured by Artec Spider.

It is not advisable to use smooth fusion for bones, or a fast fusion which can lead to a higher error on the surface. Implement a fast fusion only to check if there are big holes in the 3D digital model with outliers removed. This will localize potential areas that will need to be scanned again. The use of fast fusion will save time, since a sharp fusion may require more time for completion. Upon completion, the fast fusion model can be eliminated. If the model presents with large holes, scan the missing areas again and repeat previous steps to

create another 3D digital model.

Sharp fusion options: You can choose to automatically fill holes by radius, watertight or manual method (User Guide Artec Studio 11: 107-109). Fill automatically by radius if the holes are small. Deep features, such as sacral foramina and the space between teeth, may not be captured by the scanners leaving a hole. Using a fill automatically may lead to an incorrect representation of these features.

If the 3D digital model has holes on surface areas where you have captured triangulation points, it may be contributed by the standard deviation (SD) values in the function to eliminate outliers, and/or the diameter value in sharp function filling holes option. If one or both values are increased and a new 3D digital model created, it may show the missing surface. However, it may be increasing potential error in the 3D digital model. Re-scanning missing surface areas can help address this issue.

If the 3D digital model is quite heavy and the project requires a lot of RAM data, it will make it difficult to manipulate the model. You can unload individual scans to free RAM by clicking with the right button of the mouse on each scan and selecting the unload option.

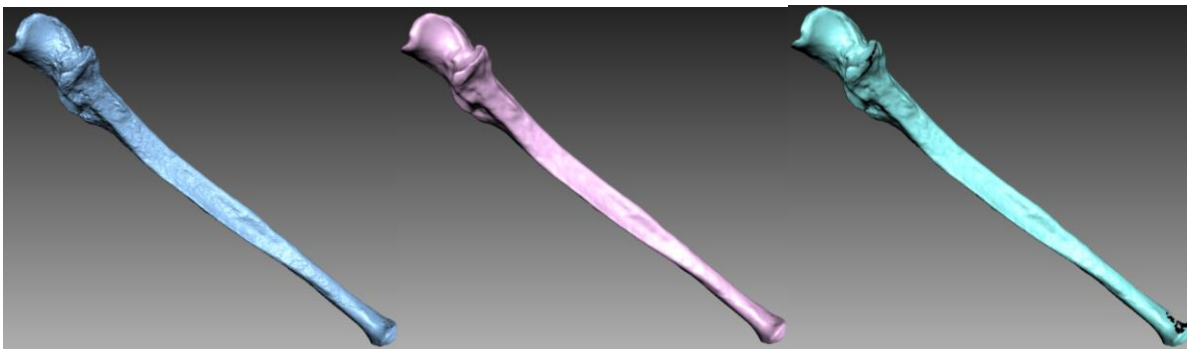


Figure 12. Sharp (left), smooth (middle) and fast (right) fusions.

18. If manually filling was selected for the sharp fusion, this selection will lead to the edges option (which can also be found on the left menu and on windows). Firstly, do a small object filter in tools to eliminate possible objects outside the 3D bone model. This will diminish the number of holes to fill and make the filling process less time consuming. Secondly, in edges, select each hole, which will appear in yellow. If no problem is found, click in fill holes. It is also possible to locate each hole by clicking directly on the model. (User Guide Artec Studio 11: 111-114).

If the hole is filled incorrectly, click on the undo button and leave it unfilled. Consider using a different software, such as Geomagic Wrap, which provides other options that respect the geometry of the model. Manual filling in Artec Studio may not be appropriate to fill the foramina at the sacrum, since it does not recognize the tunnel shape of the foramina and fills the holes anteriorly and posteriorly. However, both Geomagic Wrap bridge filling and complete filling options helps to fill in a more appropriate way to help form the foramina. It works very well for 3D monochromatic models. For textured models, Geomagic Wrap will

attribute an artificial colour to the filled areas.

For non-captured areas where the scanner cannot collect data, like deep and narrow structures such as the nasal cavity, a hole will exist. It is not appropriate to reconstruct by filling the hole. You may use the smoothing edges function to round and smooth the margins of the hole.

19. Use the small object filter in tools to eliminate potential objects outside the 3D model of the bone. (User Guide Artec Studio 11: 106-107, 111). Additionally, the option repair on windows will check if there are errors on the surface (User Guide Artec Studio 11: 110-111).

20. If the 3D model is heavy with triangulation/polygon points, it may make it difficult to operate the model. In this case the mesh simplification option in tools should be used.

Start by duplicating your sharp fusion 3D model. Perform mesh simplification (Fig. 13) and other post process steps on the copy. Retain the original 3D model without any modifications. Select mesh simplification with accuracy and an error of 0.01mm. Keeping the boundary on will better preserve the 3D model boundary and avoid shape alterations. Please note that it may still produce a heavy model. If mesh simplification is performed without maintaining the boundary borders, a higher reduction of the polygon points will make it easier to operate the model but with the risk of altering the model shape. If you attempt to perform texture before mesh simplification Artec Studio will indicate that it will take a longer time to proceed (User Guide Artec Studio 11: 114-116).

If the model is still heavy after doing the regular mesh simplification, you can perform a fast mesh simplification in a copied regular mesh simplified model. With fast mesh simplification, you can select the number of polygons the model can have (max: 65000). Fast mesh simplification will only be concerned in decreasing the number of polygons which may have a significant effect on the shape of the model, leading to a loss of detail. Regular mesh simplification is not only concerned with reducing the number of polygons. It will also attempt to maintain the shape of the model, as it will decrease the number of polygons in regular features and not in features with more detail. That is why the regular mesh simplification should be performed first while the fast mesh simplification should be done afterwards, only if it is not possible to manipulate the model.

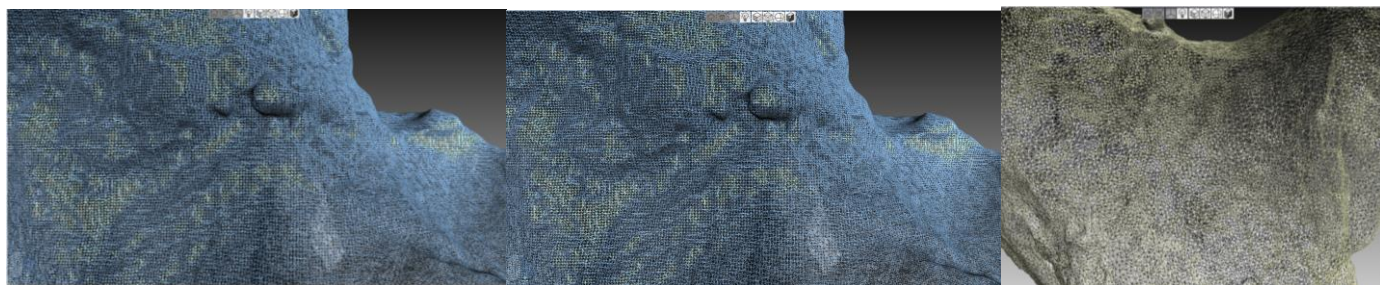



Figure 13. Triangulation points before (left image), after with keeping boundary borders (middle image), and after without keeping

boundary borders (right image) mesh simplification.

If it is not possible to perform mesh simplification and an error message appears, it may be due to an erroneous alignment between scans. Confirm whether one or several scans are misaligned in the model even if you don't get an error message (Fig. 14). If misaligned scans are present, locate the scan(s) which have the area in question. Then re-align the scan(s) again. Repeat post process steps from global registration.



Figure 14. Misaligned scans (error inside red circle).

21. If small surface error is present, consider using editor options for smoothing. Be assured that every action can be undone with the undo button  (User Guide Artec Studio 11: 81-91).

22. You can apply Texture to create a coloured 3D model. It can also be saved as a monochromatic model by exporting as a .stl file (or by performing the scan without capturing texture) (User Guide Artec Studio 11: 117-122).

To correct texture, go to editor (left menu) to select texture-healing brush (Fig. 15). Be aware that it is not possible to undo each step on the texture-healing brush. If you make a mistake, just click cancel and start again. (User Guide Artec Studio 11: 122-123).

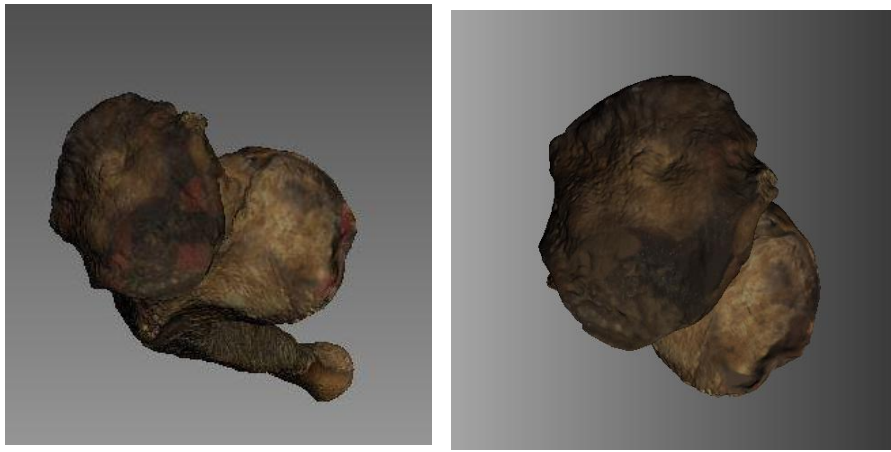


Figure 15. Left image: texture error in red. Right image: Texture after using the texture-healing brush.

23. Save the project to file or in the right menu (User Guide Artec Studio 11: 35, 40, 67-68, 75-76, 141-143). The project can be saved anytime during the scanning and post process procedures. Models can also be exported, for example as an .obj file with a textured model, which can be used in other software (User Guide Artec Studio 11: 68-71, 143).

24. You can perform non-geometric measurements (left menu), such as linear distances (User Guide Artec Studio 11: 130-136, 144). By using linear measurements, it provides coordinates (values X,Y,Z) for each point along with distance values.

25. Deviation: In order to compare two models of the same bone, use the Surface-distance map (located in the measures panel). (User Guide Artec Studio 11: 136-139).

Simplified guidelines to create 3D digital models of skeletal remains:

- 1) Allow the scanner to warm up (only for Artec Spider).
- 2) Scan each surface of the bone.
- 3) Eliminate noise in each scan.
- 4) Align the scans.
- 5) Perform global registration.
- 6) Eliminate failed frames and frames with an elevated error.
- 7) Remove outliers.
- 8) Perform a fast fusion. Check for holes in the model.

- 9) If large holes are present, scan the missing areas.
- 10) Eliminate noise in the new scans and then align them with the previous scans.
- 11) Perform global registration and then eliminate failed frames afterwards.
- 12) Remove outliers.
- 13) Perform a sharp fusion to create a 3D digital model.
- 14) Create a copy of the model to fill small holes if necessary in edges. Perform all post process procedures on the copy of the model.
- 15) If the model is heavy, perform a regular mesh simplification first. If the model remains heavy, create another copy to perform a fast mesh simplification.
- 16) Put texture into the copy of the model (last model created)
- 17) If desired, you can correct texture errors in editor.
- 18) Don't forget to save your project and the scan as .obj or .stl files.

Acknowledgements: I would like to thank the Department of Archaeology from the University of Sheffield for allowing me to use the Artec Spider and Eva scanners. I am grateful for the opportunity to scan their curated skeletal remains, with pictures of some of created 3D digital models featured in the present guidelines. I appreciate Central Scanning Ltd and Artec 3D for answering my scanning questions, especially Alex Chung. I would also like to thank Kevin Kuykendall, Elizabeth Craig-Atkins and Jackson Ng for their comments which helped improve these guidelines.

Other resources:

Tutorial videos of how to scan a deer skull with Artec Spider:

<https://www.youtube.com/watch?v=uCITFPF2sLg>
<https://www.youtube.com/watch?v=Hh4R-fgbzVI>
<https://www.youtube.com/watch?v=H1QH8vMcf7w>
<https://www.youtube.com/watch?v=mdfBqh3b7w4>
https://www.youtube.com/watch?v=8BBh_m6z9Gw
<https://www.youtube.com/watch?v=FtuuYYuXDzs>

Blog post - 3D scanning in extreme conditions of African desert: A novice's success story

<https://www.artec3d.com/news/precision-3d-scanning-in-paleontology>

Review articles: Artec Eva & Space Spider

<http://www.develop3d.com/reviews/review-artec-eva-spacespider-3D-scanning>

<https://www.artec3d.com/news/3d-scanning-hard-to-scan-objects-on-halloween>