Corrective Hybrid 3D Digitization

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Problem statement

The application of accurate 3D acquisition technologies in cultural heritage has proven to be beneficial in many aspects, such as data collection, analysis, preservation, and education. There are several 3D scanning methods available, each with its own set of strengths and limitations. The effectiveness of a method often relies on the object's characteristics. When it comes to 3D digitizing intricate, structurally complex and delicate objects, a number of challenges may arise. Factors such as size, geometric complexity, thickness, reflectance, occlusion and transparency or translucence can all influence the effectiveness of a method and can introduce severe errors in the process. Zooarchaeological finds, such as animal bones or seashells typically exhibit at least one of the above problematic characteristics, making them challenging to digitize (Spyrou et al., 2022).

In this work, we propose a methodology, based on proven algorithms to combine multiple 3D models of the same physical object acquired with different digitization approaches, in order to take advantage of the merits of each method and rectify problematic scans by selectively combining and fusing surfaces.

Methodology

The proposed pipeline is presented in the following figure. Below we briefly outline the steps involved.

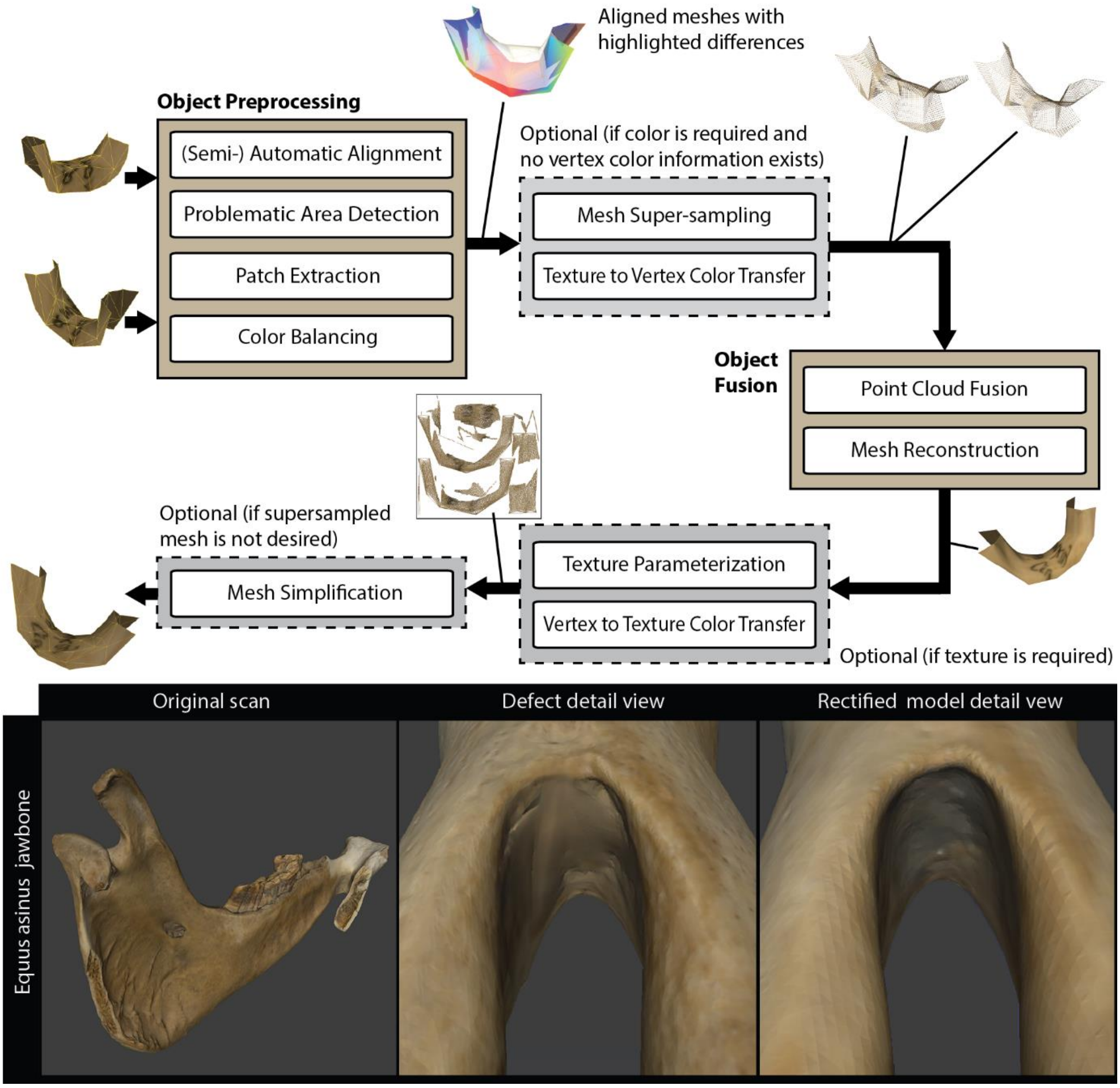
Input. The pipeline takes as input two or more meshes of the same object, digitized with different approaches and proceeds with the detection of mismatched regions on their surfaces. In our case study, we used the two most popular approaches, i.e. structured light scanning and structure from motion.

Output. The result of the process is a mesh with texture (depending on the input), where problematic surface areas have been replaced using the best candidate surface from the alternative digital versions to the original (defective) scan.

Object preprocessing. For each artefact or specimen, the most reliable digitization source is used as reference to align the other version(s) and act as the model to be rectified. Computational alignment is a very crucial part of the process and must be carefully supervised, at least when using a standard local average error minimization approach, as available in Meshlab (Ranzuglia et al., 2013).

Problematic patches are removed and replaced with the corresponding parts from the secondary source(s): After, alignment, major surface deviations can be detected and visualized and the user determines which parts should be retained from each digital version. Optionally, if texture is present on the input geometry in the form of bitmaps, surfaces are super-sampled and texture is transferred to the digitized point cloud. Super-sampling is necessary to ensure that point cloud density conforms to the spatial granularity of the texture applied to the surface.

Object Fusion. The high-detail point clouds containing the geometric and color information of the retained parts is fused to create a new 3D mesh, using the Screened Poisson reconstruction method (Kazhan and Hoppe, 2013). The reconstruction method requires oriented point samples, but these are available by construction, since the input comes from surface data.



Outline of the corrective hybrid 3D digitization pipeline and an example of a case study.

If the output model requires texture maps, a new surface parameterization is generated and color for the texture atlas is sampled from the dense point cloud. The resulting mesh can be optionally simplified to match the original density of the input models.

We implemented the entire pipeline in Meshlab (Ranzuglia et al., 2013) with the exception of the texture parameterization step, for which other modelling software have been proven more effective.

Evaluation and results

We specifically focused our case study on three diverse, problematic and hard to digitize zoological specimens, which are used in zooarchaeology for comparative study. These have been first carefully digitized with a high-precision structured light scanner with color capture. A second digitization stage, using structure from motion (SfM) photogrammetry, was performed on objects on which defects on the 3D models were identified. The structured light scanned models were used as the primary meshes (to be corrected) and reference models for quantitative measurements. In the case of SfM digitization, we specifically concentrated more shots on the problematic areas of the specimens. The output of the SfM reconstruction was used to patch the results of the structured light data.

We successfully performed corrective hybrid digitization using structured light scanning and photogrammetry on the zoological specimens and evaluated the results against measurements from the original objects and the primary scanned data.

Qualitative analysis. The three subjects were evaluated against the original specimens and the structured light 3D model in terms of improvement of the captured geometry and surface coverage, geometric consistency, presence of artifacts, texture and detail preservation.

The original scans exhibited mismatched surfaces and under-sampling in blade-like thin structures, bridging artifacts in high-occlusion areas (see example in the figure), skewed elongated structures and holes at very thin parts.

Most artifacts were successfully corrected using complementary, healthy parts from the SfM reconstruction. The only exception was the patching of holes on a seashell sample, which, although successful, lead to the generation of new holes at a different location. Still, these artifacts were less pronounced than those on the original mesh. Textural information and general mesh integrity were preserved consistently.

Quantitative analysis. All corrected specimen meshes exhibit a near-zero distance from the original scans on the parts that were not replaced, indicating no error from the surface reconstruction stage. Results were found to improve mesh quality, while sufficiently preserving texture information.

It is important to note here that the proposed process for repairing problematic scans is not dependent on a particular digitization method. We have conducted experiments on scanned objects with structured light technology and structure form motion photogrammetry, but the approach is just as well applicable to any method that can generate a surface model with or without texture, such as isosurface extraction from Micro CT or Neural Radiance Fields.

References

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