Integrating Photogrammetry and Micro-CT Data for Surface Detail Transfer in Multimodal 3D Reconstruction

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Problem Statement

Multimodal 3D reconstruction has long sought to achieve a balance between geometric accuracy and photometric realism. Volumetric imaging methods such as Computed Tomography (CT) have been widely applied to archaeological and biogenic materials to produce accurate representations of external and internal structure, features otherwise inaccessible through conventional observation or invasive methods. CT reconstructions, however, lack the optical properties that define the visual appearance of a surface and therefore remain limited in visual realism. Conversely, image-based methods that synthesize three-dimensional geometry from optical data, such as Structure from Motion (SfM), can effectively capture details, color variations, and surface textures, excelling in the reproduction of challenging aspects such as specular and chromatic appearance. Nevertheless, they cannot record volumetric or subsurface features, highlighting the need for hybrid solutions that combine optical and volumetric data sources.

In this study, we assess the integration of two reconstructive techniques, with the goal of transferring surface detail information from photogrammetric reconstructions onto CT-derived isosurfaces. The proposed hybrid approach seeks to merge the geometric fidelity and volumetric accuracy of CT imaging with the high-resolution surface texture, microtopographic detail, and color information obtained through photogrammetry, thereby improving both the visual and structural representability of reconstructed models, in line with recent advances in cross-modal registration between CT volumes and 3D point clouds (Saiti and Theoharis, 2022).

Methodology

Building on earlier multimodal integration efforts combining photogrammetry and computed tomography for complete 3D digitization (Zhan et al., 2021), the proposed workflow integrates volumetric and image-based reconstruction techniques to facilitate the transfer of true color, surface detail, and occlusion between complementary datasets.

The first stage of the workflow employs two differential meshes representing the same object: a volumetric model extracted through isosurface reconstruction from micro-CT data, and a photogrammetric model derived from image-based modelling. Micro-computed tomography (micro-CT) was initially used to nondestructively document the structural geometry and shape of the artefact. Voxels generated through Xray attenuation were reconstructed into a continuous volumetric dataset from which a three-dimensional isosurface was produced. CT reconstructions offer high geometric accuracy but lack the optical properties required for realistic visualization, as scanners record density variations rather than true surface color or reflectance. To complement the volumetric dataset, an image-based reconstruction was generated through photogrammetric methods designed to produce a dense point cloud and textured mesh. The resulting model provided the color information used during the detail transfer process to encode surface characteristics related to light interaction, including diffuse reflection, specular response, and microstructure. The next stage of the hybrid pipeline implements both CT and SfM-derived meshes and addresses the specific challenges each modality presents, stemming from morphological discrepancies and sampling density differences between reconstruction methods. Both datasets were inspected for alignment accuracy, simplified for handling, and spatially co-registered to establish a consistent coordinate framework, ensuring that subsequent processes such as parametrization and reprojection could be accurately performed. An essential preparatory stage involves surface re-parameterization, defining the correspondence between the three-dimensional surface and the mapped UV coordinates within the two-dimensional texture layout. The importance of precise surface parametrization for maintaining fidelity during texture reprojection has also been highlighted in recent work on improving texture mapping of photo-reconstructed models (Maggiordomo et al., 2021).

The final stage focuses on transferring microstructural and photometric detail from the SfM reconstruction onto the CT-derived isosurface, integrating both geometric and optical data. Color information and surface detail from the photogrammetric model are transferred onto the CT-derived mesh through texture reprojection, with the former serving as the source mesh and the latter as the target geometry. Two established approaches may be employed in this phase, the first relies on ray casting and texture baking, in which color, normal, and reflectance data are projected from the source to the target via UV correspondence, effectively preserving lighting and material cues from the image-based model. The second follows a geometry-driven interpolation strategy, where color information is propagated across corresponding vertices within the dense point cloud before being reprojected into texture space. Both methodologies are effective and can be implemented across different 3D software environments, though their suitability depends on the specific objectives and data characteristics of each reconstruction.

Evaluation and Results

The evaluation of our case studies was based on two optically challenging specimens, one displaying strong surface reflectivity due to resin impregnation and the other featuring a semi-translucent structure prone to internal light diffusion. Such materials typically hinder photogrammetric digitization, as specular highlights and subsurface scattering often cause local geometric distortions and color inconsistencies, which in turn affected parts of the workflow and led to minor surface irregularities in specific regions.

Qualitative analysis. The two subjects were evaluated in terms of structural coherence between the volumetric and image-based datasets, with a strong focus on the preservation and accurate transfer of surface texture onto the fine geometry of the isosurface. The hybrid reconstruction approach demonstrated strong visual consistency between modalities, with well-preserved surface color transfer and geometric wrapping across the reconstructed areas, though some localized discrepancies were observed in regions influenced by material properties. Nevertheless, the overall topology of the isosurface remained stable, with only minor visual irregularities appearing in areas where texture constraints introduced slight distortions.

Quantitative analysis. All evaluated reconstructed meshes exhibited minimal geometric deviation between the volumetric and image-based reconstructions, indicating accurate correspondence and stability across modalities. The results confirmed that surface detail and color information were successfully transferred without compromising the geometric precision of the isosurface, while maintaining overall photometric consistency.

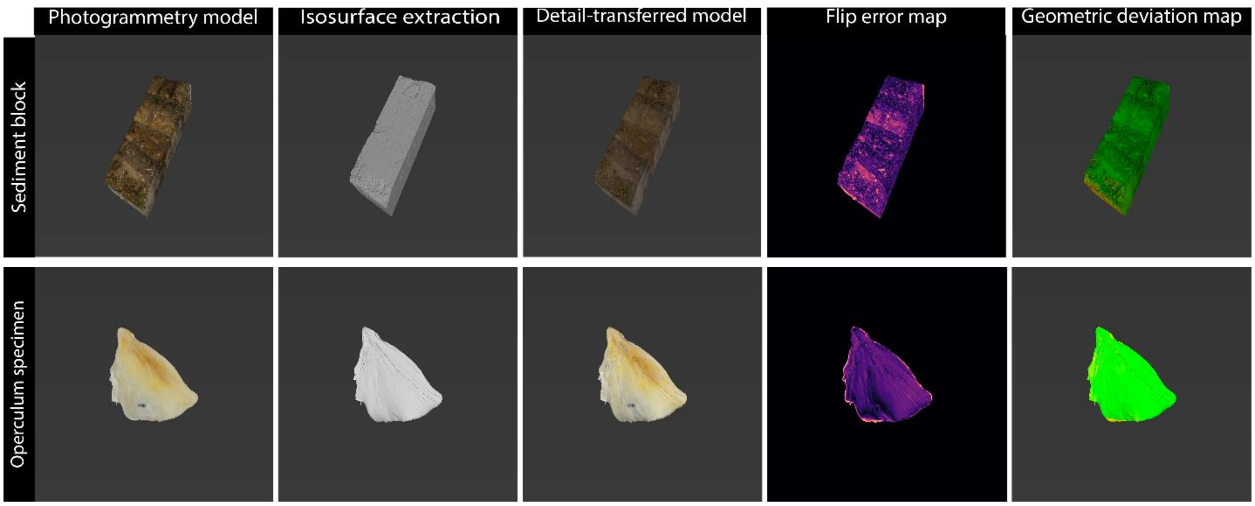

Figure 1. Comparative visualization of the two case studies: a resin-impregnated sediment block (top row) and a semi-translucent operculum specimen (bottom row). From left to right: photogrammetric reconstruction, CT-derived isosurface, detail-transferred model, FLIP perceptual error map, and geometric deviation map illustrating cross-modal correspondence.

References

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