ERROR ASSESSMENT IN IMAGE BASED 3D RECONSTRUCTION AND 3D PRINTING

Avinash K. M. G. Kotla (1), Samarth S. Raut (1)

Department of Mechanical, Materials and Aerospace Engineering, Indian Institute of Technology Dharwad, Dharwad, Karnataka, India.

Introduction

Patient-specific implants and three-dimensional geometric anatomical models reconstructed from medical scans are essential for appropriate clinical diagnoses and treatment [1]. 3D printing helps create physical replicas that benefit surgical planning and training, drug development, and several other avenues of biomedical applications and 3D virtual models are essential for computational mechanics and AI-based inferencing. However, the 3D printed implants and objects carry the accumulated geometrical errors that creep in during different stages of the image-based 3D reconstruction and 3D printing process pipeline, e.g., discretization errors in imaging and segmentation, 3D reconstruction, and 3D printing [2]. Shape similarity studies, biomechanical computational simulations and surgical implants and planning are adversely affected due to inaccuracies in reconstructions [3]. In the case of patient-specific anatomical models, error calculation is debatable as the ground truth is unavailable. To explore these aspects, the current work considers the complete reconstruction pipeline applied to a 3D-printed sphere, facemask, and abdominal aortic aneurysm (AAA). Here we present a systematic approach to investigate errors and validate the process protocol. Normalized error in surface area (NESA), root mean square error (RMSE) and maximum local error (MLE) are reported to assess the overall impact of the selected protocol on respective representative geometry. Some factors that warrant further detailed exploration to assess their influence on errors in geometric reconstruction are identified.

Methods

The CAD model for the sphere was created using SolidWorks® software (version 2022) and was meshed using the open-source meshing tool Gmsh to obtain a fairly uniform triangular surface tessellation. The model for the facemask was sourced from an open-source online repository. The surface mesh file for AAA was sourced from previously published work [4]. All the individual geometries fit within a 35 mm cubic space. Segmentation errors were easily avoidable due to bimodal histogram signifying sufficient contrast. 3D-printing, followed by micro-CT imaging and 3D reconstruction was used to explore the reconstruction pipeline, using three distinct geometries. Formlabs Inc. Form 3+ 3D printer was used to 3D print the models (85 microns laser spot size and 25 microns layer height). The printed resin models were post-processed as per manufacturer recommended parameters. The printed models were scanned using Quantum GX2 micro-CT imaging facility available at IISER Pune. Two-component Gaussian Mixture Model was used to automate image segmentation. The marching cubes algorithm and Trimesh were used to extract the isosurface and to create the surface mesh respectively.

Results

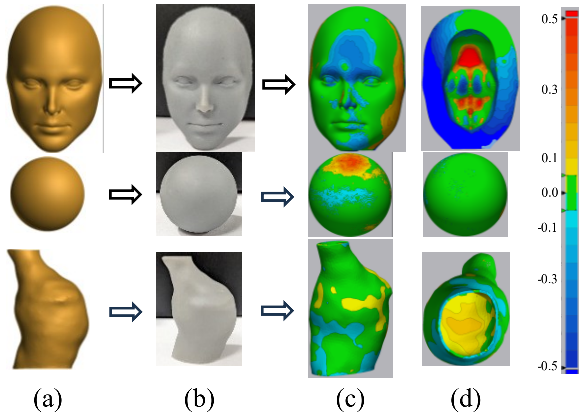

Figure 1: (a) Reference models, (b) 3D printed models, (c), (d) Comparison of reference and reconstructed models

Figure 1 shows the reference models, 3D printed models and the global comparison of the reference and reconstructed models. Errors are tabulated in Table 1.

Error metric	Facemask	Sphere	AAA
NESA	3.32	4.38	0.056
RMSE (mm)	0.0984	0.156	0.0384
MLE (mm)	0.4106	0.806	0.1587

Table I: Error metrics capturing accumulated errors

Discussions

NESA and RMSE are comprehensive global error metrics, while MLE is local. Higher errors in sphere are due to relatively large external patch containing dimples caused by support structures used in 3D printing. Interplay between voxel resolutions, native geometric features, tessellation parameters such as normalized average edge length, mesh smoothing and 3D printing configurations was noticeable. AI may help to tailor this process intelligently specific to the geometry.

References

1. Doi et al., Comp. Med. imaging and graphics, 31 (4-5), 198-211.
2. George et al., Radiographics, 37 (5), 1424-1450.
3. Steinman et al., J. of Biomech. Engg., 135 (2), 2013
4. Raut, PhD diss., Carnegie Mellon University, 2012.

Acknowledgements

Funding: SERB-SRG (Dept. of Science and Technology, Govt. of India) grant SRG/2020/002513; Micro-CT: NFGFHD, IISER PUNE (DBT, Govt. of India, grant number BT/INF/22/SP17358/2016).