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An In-house 3D Surface Scanning System for Collision Detection Application in Radiotherapy

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ABSTRACT

Purpose: A novel, low-cost 3D surface scanning system was developed using a custom modification of the laser-profiling technique. Proof of concept was demonstrated through 3D simulation in Blender 3D software. A real-world prototype was then implemented using a consumer-grade camera and the existing laser in the CT simulation (CT-Sim) room.

Methods: A single laser line source and multiple cameras were used, with the laser and cameras intentionally separated—unlike conventional laser-profiling technique. The cameras were placed at optimized angles and distances to enhance visibility and reduce occlusion. The cameras captured the laser projected onto the object being scanned to extract 3D surface information. For simulation, Blender 3D was used to build a digital twin of the setup and emulate the laser within the CT-Sim to image a human-like digital phantom. For the real-world prototype implementation, a foam phantom was placed on the CT-Sim table, and a tripod-mounted camera recorded the laser projection during table motion at 120 fps in 4K. Intrinsic and extrinsic camera calibrations were performed using a checkerboard pattern. For validation, the 3D mesh of digital phantom and a 3D scan of the physical phantom, obtained with a commercial 3D scanner, served as ground-truth. The image-processing pipeline was implemented in Python, and 3D surface analysis was performed in CloudCompare software.

Results: Simulation results showed an excellent agreement between the reconstructed 3D point cloud and ground-truth mesh of the digital phantom with mean±SD of -0.1±0.8mm. For the physical phantom, the reconstructed 3D surface agreed with the ground truth with mean±SD of -0.48 ± 1.2 mm.

Conclusion: We have successfully demonstrated a cost-effective and accurate 3D surface scanning system using the laser source in the CT-Sim room and consumer-grade camera. This system can be integrated into the current clinical simulation workflow to produce the 3D surface of patients and immobilization devices for collision detection purposes.

INTRODUCTION

In this project, we developed and validated a proof-of-concept design of affordable, and accurate 3D surface scanning system. The innovation of this system is its low-cost, accuracy, and seamless integration within the current CT simulation workflow by utilizing the readily available laser in CT-Sim and consumer grade cameras. This is a key step to extract the 3D surface of the patient and immobilization devices to perform clearance checks and avoid potential collisions between patient and treatment machine.

METHODS AND MATERIALS

A single laser line source and multiple cameras were used, with the laser and cameras intentionally separated—unlike conventional laser-profiling technique. The cameras were placed at optimized angles and distances to enhance visibility and reduce occlusion. The cameras captured the laser projected onto the object being scanned to extract 3D surface information. For simulation, Blender 3D was used to build a digital twin of the setup and emulate the laser within the CT-Sim to image a human-like digital phantom.

For the real-world prototype implementation, a foam phantom was placed on the CT-Sim table, and a tripod-mounted camera recorded the laser projection during table motion at 120 fps in 4K. Intrinsic and extrinsic camera calibrations were performed using a checkerboard pattern. For validation, the 3D mesh of digital phantom and a 3D scan of the physical phantom, obtained with a commercial 3D scanner, served as ground-truth. The image-processing pipeline was implemented in Python, and 3D surface analysis was performed in CloudCompare software.

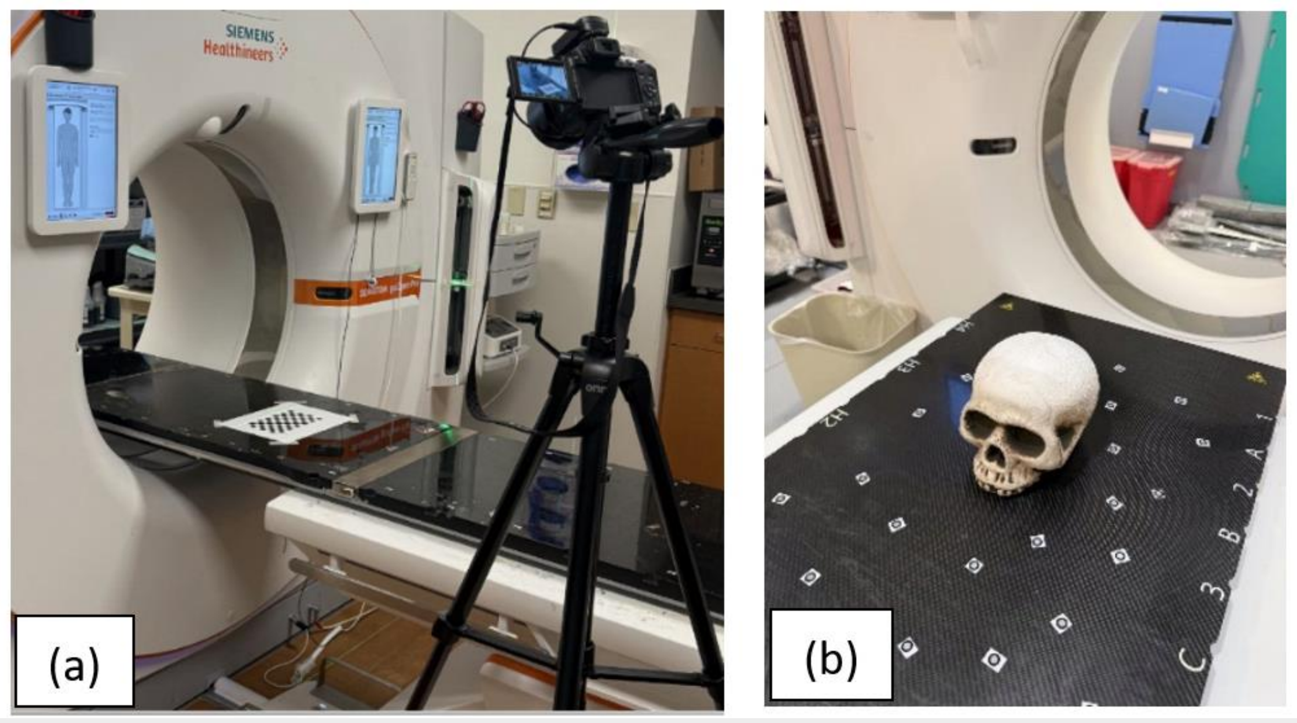

Figure 1. The physical setup of the camera, calibration checkerboard (a) and physical phantom (b)

RESULTS

Simulation results in Figures 2(b-d) show an excellent agreement between the reconstructed 3D point cloud and ground-truth mesh of the digital phantom with mean±SD of -0.1±0.8mm. For the physical phantom, the reconstructed 3D surface agreed with the ground truth with mean±SD of -0.48 ± 1.2 mm as shown in in Figures 2(e-f)

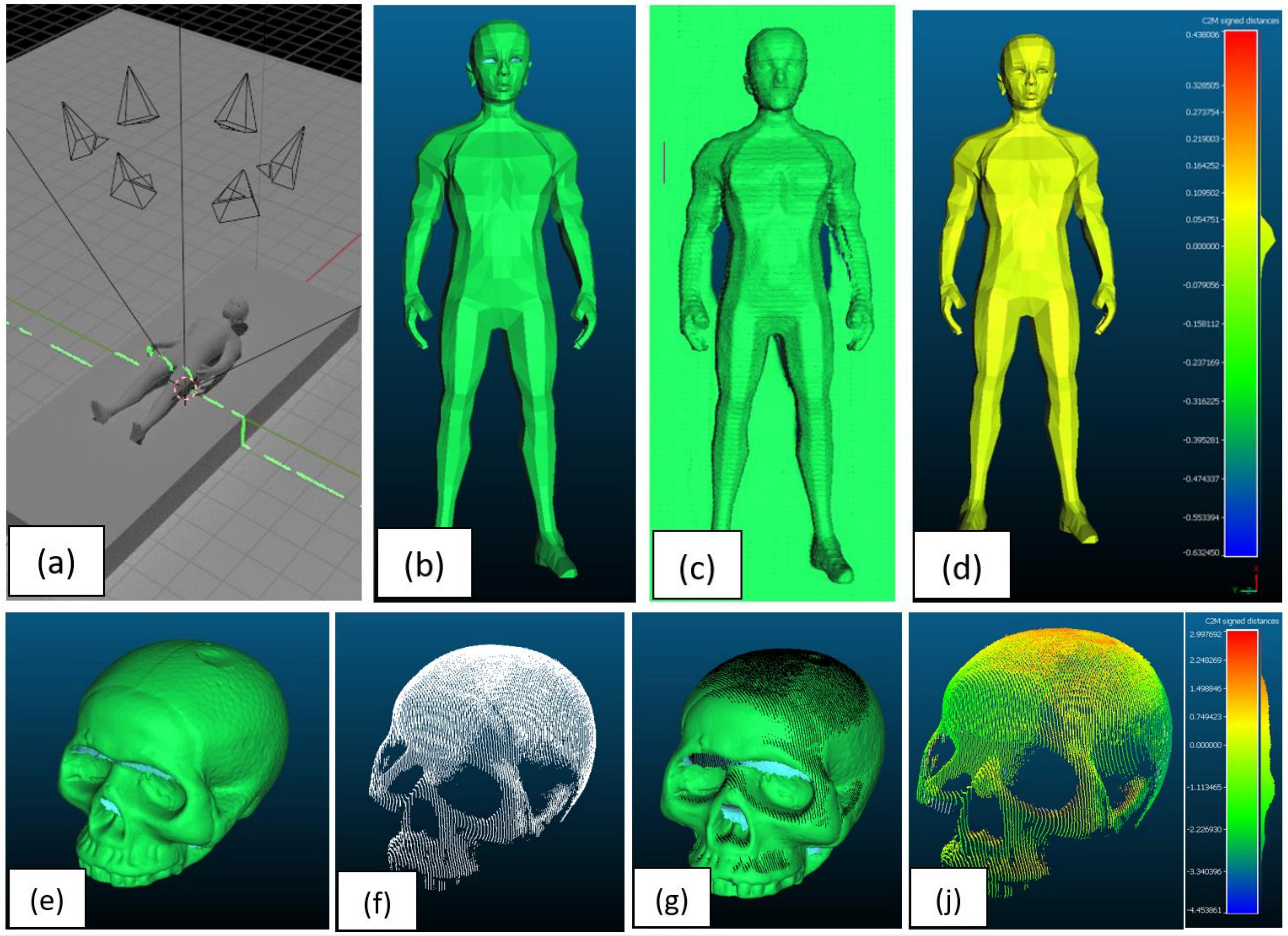

Figure 2. (a) 3D Blender scene emulating laser and cameras with the phantom on table, (b) Ground truth digital phantom, (c) Reconstructed digital phantom (our method), (d) cloud-to-mesh (C2M) distance in mm. The bottom row shows the scans and results of the physical phantom: (e) Ground truth 3D mesh, (f) reconstructed 3D point-cloud (our method), (g) co-registered 3D scans, (h) cloud-2-mesh (C2M) distance in mm.

CONCLUSIONS

We have successfully demonstrated a cost-effective and accurate 3D surface scanning system using the laser source in the CT-Sim room and consumer-grade camera. This system can be integrated into the current clinical simulation workflow to produce the 3D surface of patients and immobilization devices for collision detection purposes.

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