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An Investigation of Two Cost-Effective 3D Optical Sensing Technologies for Real-Time Collision and Monitoring for Proton therapy

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ABSTRACT

Purpose: This study investigates the feasibility of using two affordable optical surface–imaging technologies to generate detailed 3D maps of the treatment room and patient surface for detecting and mitigating potential collisions between the proton nozzle and the patient during treatment delivery.

Methods: Two optical imaging systems were evaluated: the Livox Mid-70 LiDAR, which uses a Class-I 905 nm laser with an operating range of 0.2-260m and wide circular field-of-view (FoV), and the Helios2+ Time-of-Flight (ToF) camera, which employs Class-I 850 nm laser diodes with an operating range of 0.3–8.0 m. Each system was used to acquire 3D point clouds of a gantry-mounted proton therapy vault and a volunteer. Point cloud data were processed using the CloudCompare software package for segmentation and object identification.

Results: Both systems successfully generated 3D scans of the treatment vault and subject. The LiDAR system captured a wide 70.4° FoV and provided highly detailed room-scale geometry, though the scans exhibited increased noise and flying voxels due to its limited precision (20 mm) at long operating ranges. In contrast, the ToF camera produced cleaner and less noisy scans of subject contours due to higher surface accuracy (±10 mm) but was constrained by its narrower 69° × 51° FoV and lower 640 × 480 pixel resolution. Both systems showed difficulty imaging transparent surfaces (e.g., nozzle window) and very dark materials (e.g., couch top). Multiple scans demonstrated consistent reconstruction of gantry and patient geometry relevant for collision assessment.

Conclusion: Low-cost LiDAR and ToF imaging technologies can produce sufficiently detailed 3D maps for room-scale and patient-surface modeling in proton therapy. The LiDAR system is suitable for comprehensive room mapping, whereas the ToF camera provides more accurate patient-surface capture. Their robustness to ambient light and ability to continuously scan during treatment support their potential use in an affordable, real-time collision detection system.

INTRODUCTION

This study evaluates two affordable, state-of-the-art 3D surface imaging systems to improve safety of treatment delivery. This is especially important in proton therapy, where maintaining nozzle clearance, minimizing air gaps, and preserving spot size are critical. Ultimately, this work aims to support virtual dry runs and enable remote couch movement from the treatment console.

METHODS AND MATERIALS

Two optical imaging systems were evaluated: the Livox Mid-70 LiDAR, which uses a Class-I 905 nm laser with an operating range of 0.2-260m and wide circular field-of-view (FoV), and the Helios2+ Time-of-Flight (ToF) camera, which employs Class-I 850 nm laser diodes with an operating range of 0.3–8.0 m.

Each system was used to acquire 3D point clouds of a gantry-mounted proton therapy vault and a volunteer. Point cloud data were processed using the CloudCompare software package for segmentation and object identification.

RESULTS

Both systems successfully generated 3D scans of the treatment vault and subject as shown in **Figures 1 and 2**. The LiDAR system captured a wide 70.4° FoV and provided highly detailed room-scale geometry, though the scans exhibited increased noise and flying voxels due to its limited precision (20 mm) at long operating ranges. In contrast, the ToF camera produced cleaner and less noisy scans of subject contours due to higher surface accuracy (±10 mm) but was constrained by its narrower 69° × 51° FoV and lower 640 × 480 pixel resolution.

Both systems showed difficulty imaging transparent surfaces (e.g., nozzle window) and very dark materials (e.g., couch top). Multiple scans demonstrated consistent reconstruction of gantry and patient geometry relevant for collision assessment.

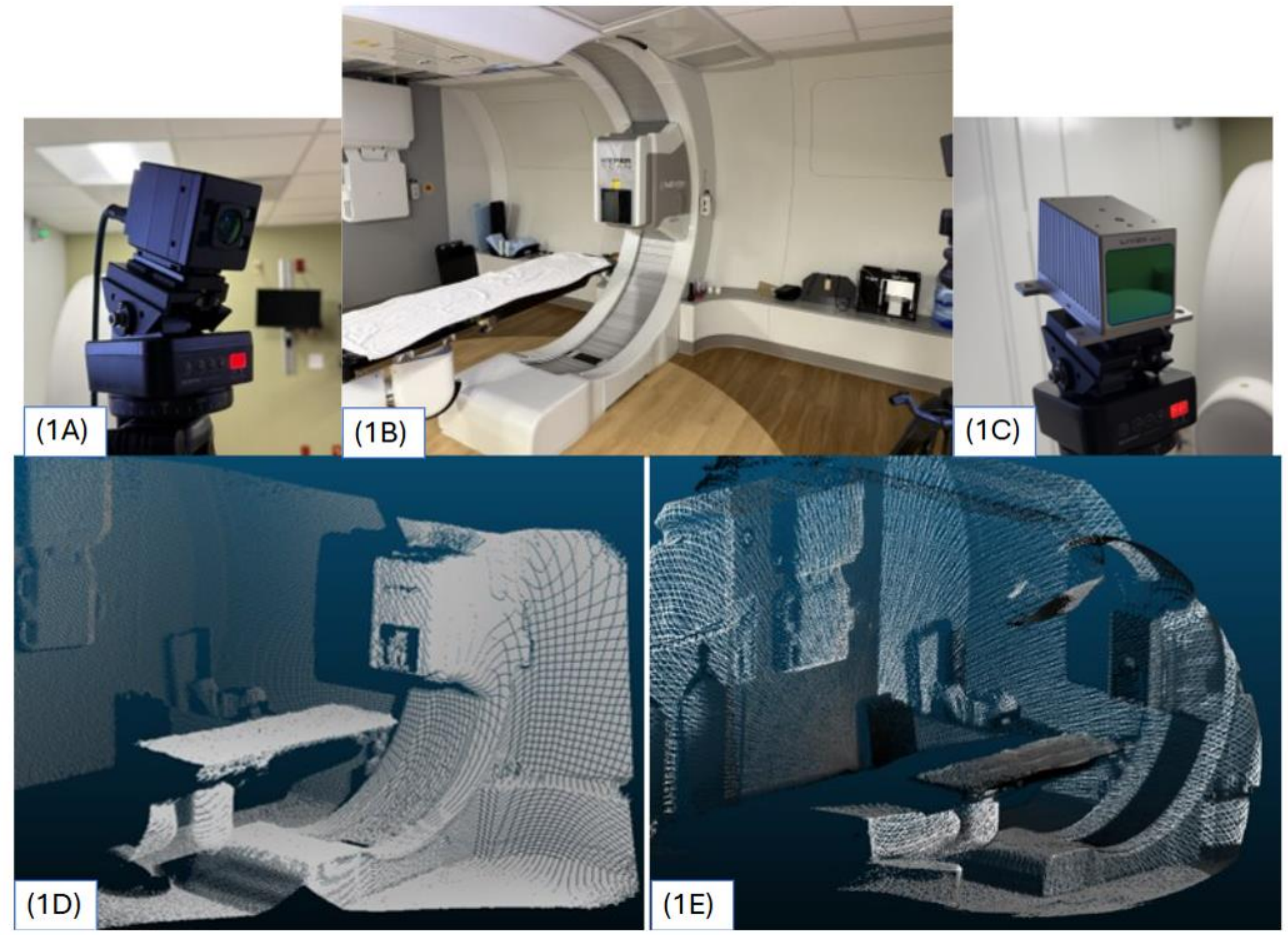

Figure 1. Figure 1A and 1C shows the Helios 2+ ToF and Livox Mid-70 LiDAR optical sensors. Figure 1B is the inner gantry and nozzle of a proton machine as seen by both cameras. Figure 1D is the 3D point-cloud representation of the scene as captured by the Helios 2+ camera. Figure 1E shows the 3D point-cloud captured by the Livox mid-70 LiDAR.m.

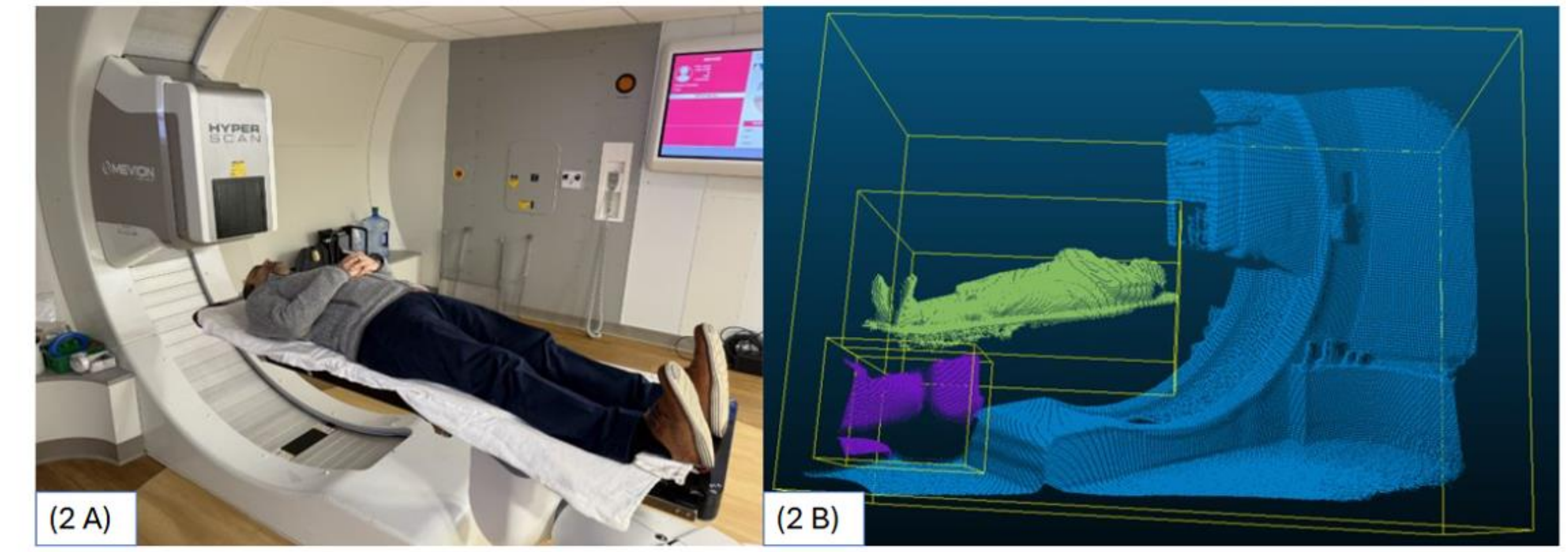

Figure 2. A volunteer laying on the robotic couch to mimic a patient in treatment position. Figure 2B shows the results of point-cloud segmentation that was generated by CloudCompare software. The segmentation shows clear separation of the robotic arm (violet), nozzle and the inner gantry (blue) and volunteer/couch (green).

DISCUSSION & CONCLUSION

Low-cost LiDAR and ToF imaging technologies can produce sufficiently detailed 3D maps for room-scale and patient-surface modeling in proton therapy. The LiDAR system is suitable for comprehensive room mapping, whereas the ToF camera provides more accurate patient-surface capture. Their robustness to ambient light and ability to continuously scan during treatment support their potential use in an affordable, real-time collision detection system.

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