

A Compact Low-Cost Optical CT Scanner for Education and Algorithm Development

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We present a compact, low-cost optical CT scanner and demonstrate its capabilities through three-dimensional reconstructions of centimetre-sized opaque and semi-transparent samples.

1 Introduction

X-ray computed tomography (XCT) is one of the most important imaging modalities for medical diagnosis, structural biomedical imaging, and non-destructive testing [1, 2, 3]. Like many other fields, XCT has been significantly advanced by deep learning, enabling substantial improvements in image reconstruction and analysis [4, 5]. However, the high cost of XCT hardware limits its accessibility for teaching and the development of novel reconstruction methods. To address this challenge, several low-cost optical CT scanners have been proposed [6, 7, 8]. Here, we present a compact optical CT scanner costing less than 300€ that is small enough to fit into a hand-luggage suitcase, providing an accessible platform for CT education and algorithm development.

2 Experimental Setup

The control system is based on a Raspberry Pi 4B with 2GB RAM (RPI) [9], which controls illumination, sample-stage rotation, and image acquisition. Illumination is provided by a 16×16 RGB LED panel (WS2812B), driven via a voltage-level shifter (TXS0108E) to match the RPI's GPIO 3.3 V logic with the panel's 5 V logic levels. A diffuser plate is mounted several centimetres in front of the LED panel. The sample stage is rotated by a NEMA 17 bipolar stepper motor with a DRV8825 driver. Microstepping enables an angular resolution from 1.8° (full step, 200 steps/revolution) down to 0.05625° (1/32 step, 6400 steps/revolution). Image acquisition uses the RPI High Quality camera with a C-mount 16 mm telephoto lens and a 12 MP Sony IMX477R sensor ($1.55 \mu\text{m} \times 1.55 \mu\text{m}$ pixels). The housing is fabricated from PLA by fused deposition modeling and measures $354 \times 170 \times 165 \text{ mm}$ (length $\times$ depth $\times$ height). Extension tubes reduce the camera-to-sample distance to approximately 150 mm. A photograph of the setup and the circuit diagram are shown in Fig. 1.

Hardware control is implemented in Python using the open-source libraries Picamera2, Neopixel, RPi.GPIO, and NumPy. CT reconstruction is per-

formed with the Filtered Backprojection (FBP) algorithm implemented in the ASTRA toolbox [10].

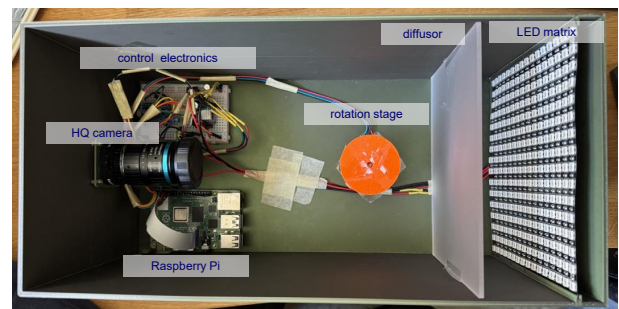


Fig. 1 A photo of the compact optical CT-scanner.

3 Results

Two samples were scanned by acquiring 200 back-illuminated projections at 1.8° angular increments over a full 360° rotation. The samples were a sliced lime and a LEGO® skeleton minifigure (4 cm height). All images were flat-field corrected following [11] and normalized to compensate for illumination inhomogeneities.

Representative projections and corresponding sinograms are shown in Fig. 2. In contrast to the opaque plastic toy, the lime is semi-transparent, revealing internal fibres and peel substructures (yellow arrow). The toy's toes remain faintly visible despite back illumination (magenta arrow), which is likely caused by scattering.

The tomographic reconstruction (FBP) of the scanned samples are depicted in Fig. 3 and Fig. 4, respectively the lime sample and the toy sample.

The lime reconstruction reproduces characteristic anatomical features. The outer flavedo appears with high intensity in the ortho-views and volume rendering, while the sagittal plane reveals the typical dimpled peel structure. Membranes separating the wedges and the central core (columella) are visible in the coronal view and volume rendering. However, the transversal plane shows that intensity is

mainly reconstructed near the surface, and sharp tissue boundaries are only partially resolved.

The opaque toy skeleton is reconstructed with its overall geometry and many fine details clearly visible in all views. High attenuation values are distributed uniformly throughout the sample, reflecting its opacity. The fine spine structure is resolved in the sagittal and coronal planes as well as in the volume rendering. Minor artifacts occur at sharp intensity transitions in the transversal plane, and a small ghosting artifact at the shoulders is likely caused by scattering.

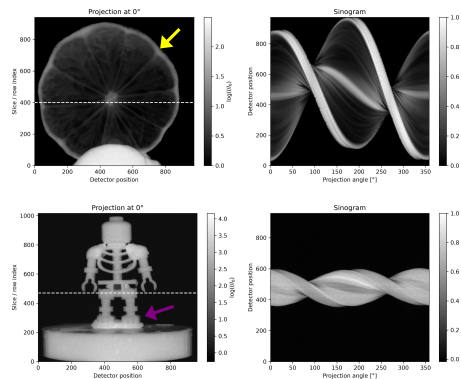


Fig. 2 (Top row) lime and (bottom row) skeleton sample: (l) projection, (r) sinogram.

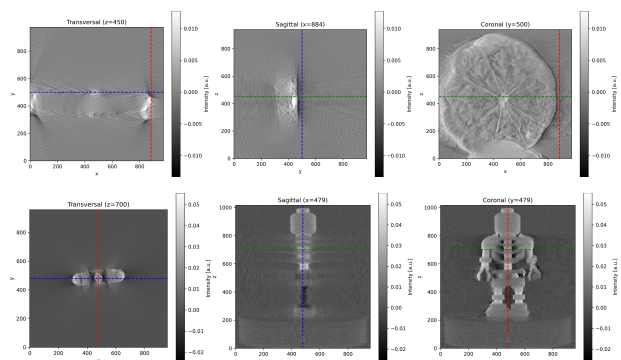


Fig. 3 (Top row) lime and (bottom row) skeleton sample: orthogonal planes.

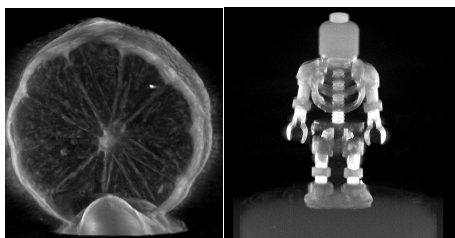


Fig. 4 Volume rendering of the lime (l) and skeleton (r).

4 Discussion & Conclusion

In conclusion, we have presented a compact, low-cost optical CT scanner capable of 3-dimensional re-

construction of opaque and semi-transparent samples. For the samples investigated here, scattering, refraction, and diffraction have only a minor influence, such that x-ray-based reconstruction remains applicable. The scanner provides a practical platform for teaching optical and tomographic principles. Moreover, its high reconstruction quality for opaque samples may facilitate the development and evaluation of deep-learning methods for CT without requiring an expensive x-ray scanner.

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