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Revolutionizing Space Exploration: 3D Scanning for Defect-Free 3D Printed Components

Introduction

- Integrating 3D printing technology in space missions represents a transformative advancement, enabling in-site manufacturing and repair capabilities. However, the reliability of 3D-printed components is challenged by the occurrence of errors during the printing process, necessitating mitigation to ensure the structural integrity and functionality of printed parts.
- This study progressed towards developing a 3D scanning system capable of working with 3D printers to ensure errors are within acceptable ranges while preserving usability. Experiments included different data acquisition methods, such as video capture and snapshot at measured steps for Laser Triangulation, alongside developing algorithms to maintain the printed material's usability.

Laser triangulation

Laser triangulation is an implementation of active stereo vision, where a laser beam is projected onto an object to be scanned. A camera is used to capture the displacement of the laser line caused by the object from a different point of view. Displacement can be then used to calculate the geometry of the scanned object such as height. A collection of multiple scans can then be aggregated to reconstruct a point cloud of the scanned object.

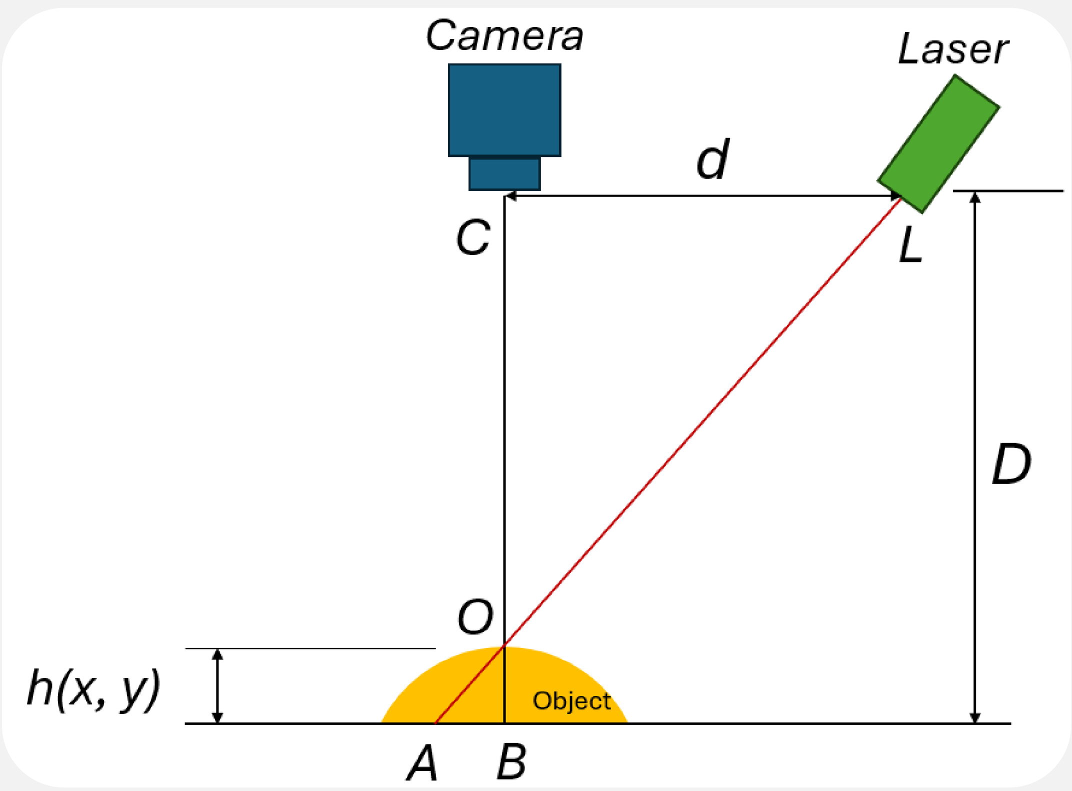
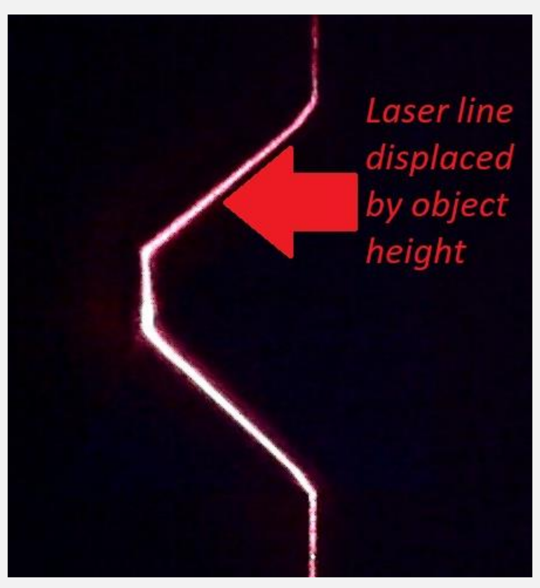
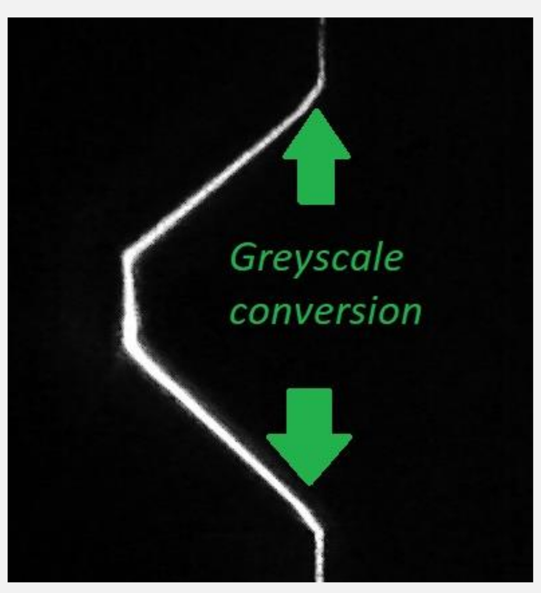


Fig 1: Optical geometry of laser triangulation

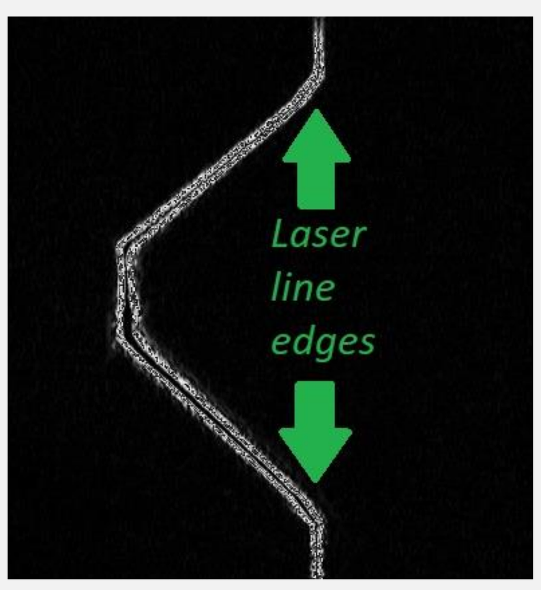
Methodology

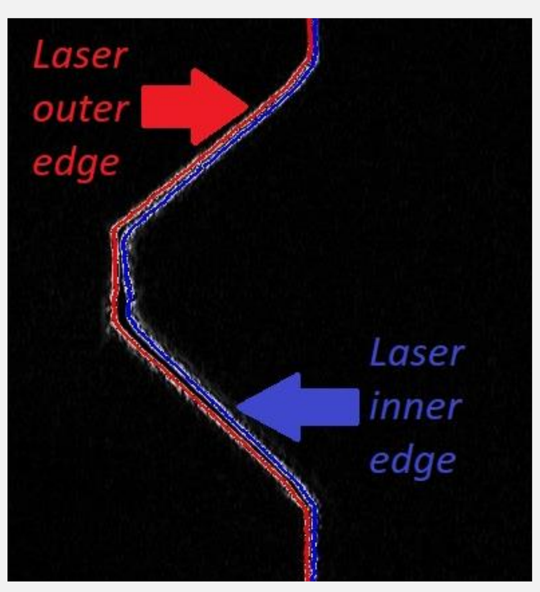
Start → Hardware setup in accordance with laser triangulation with reverse geometry → Data acquisition by taking snapshots at 1 mm → Preprocessing by RGB to Greyscale conversion using Luminosity method

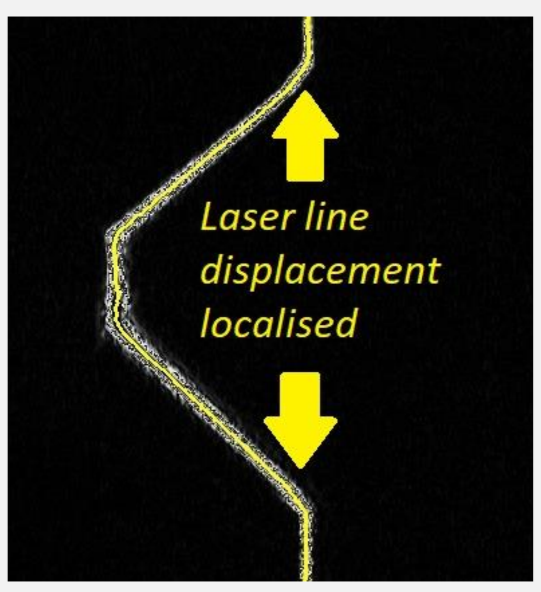




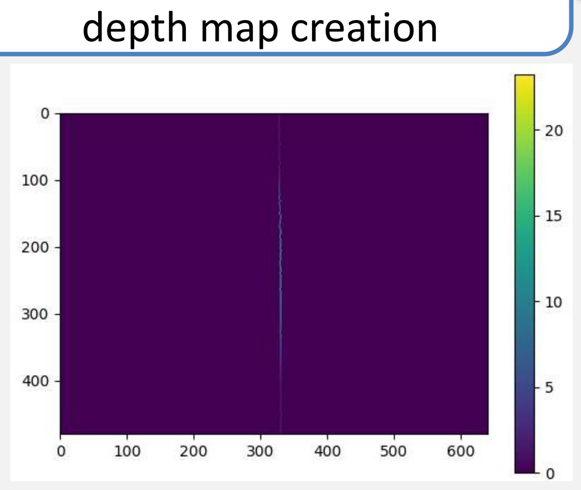
→ Laser line edge detection using Sobel X gradient → Laser line outer and inner edges by Gaussian curve fitting → Laser line localization using outer and inner edges

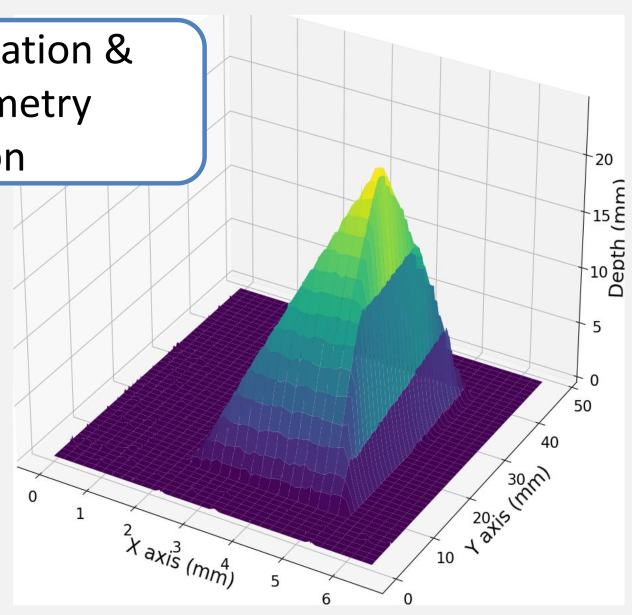






→ Height calculation using laser triangulation geometry & depth map creation → Depth map combination & print object geometry reconstruction





Results

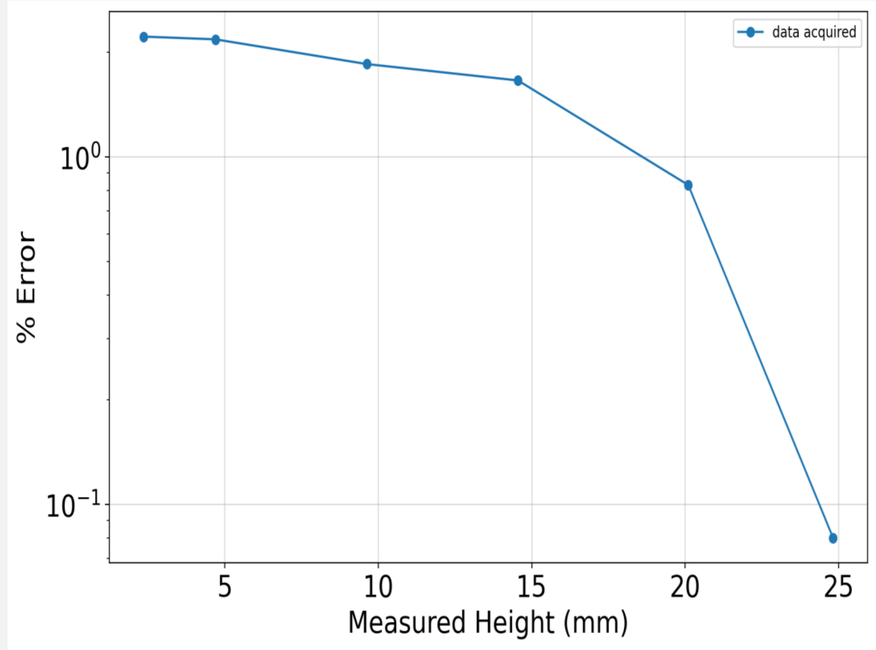


Fig 2: Relationship between % error and measured height

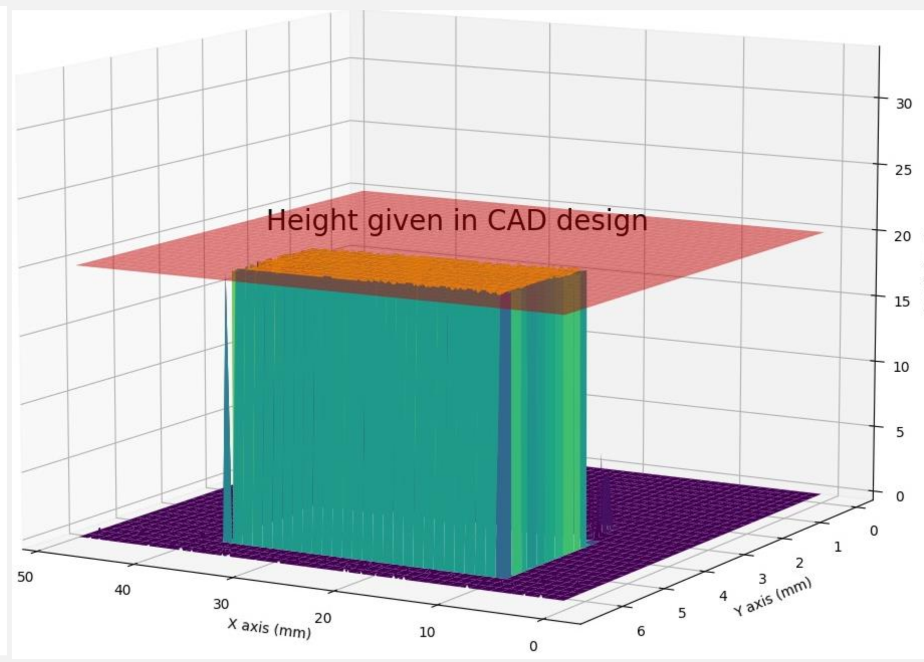


Fig 3: Height comparison between given CAD design and scanned cube

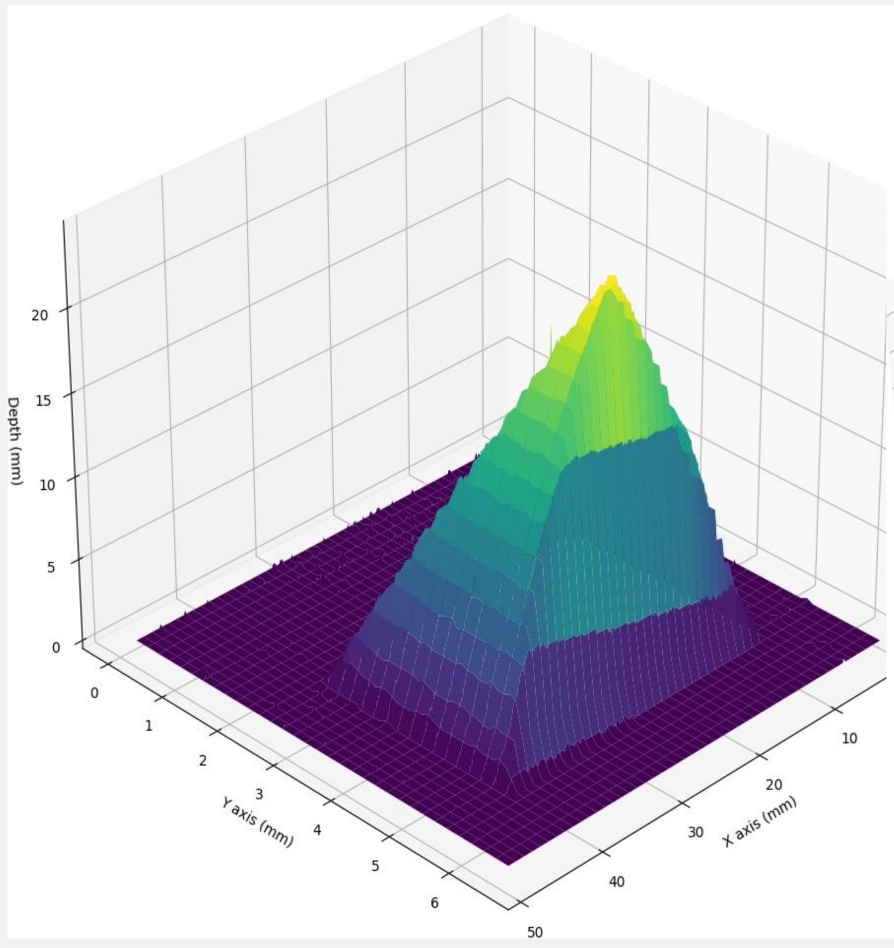


Fig 4: 3D reconstruction of pyramid

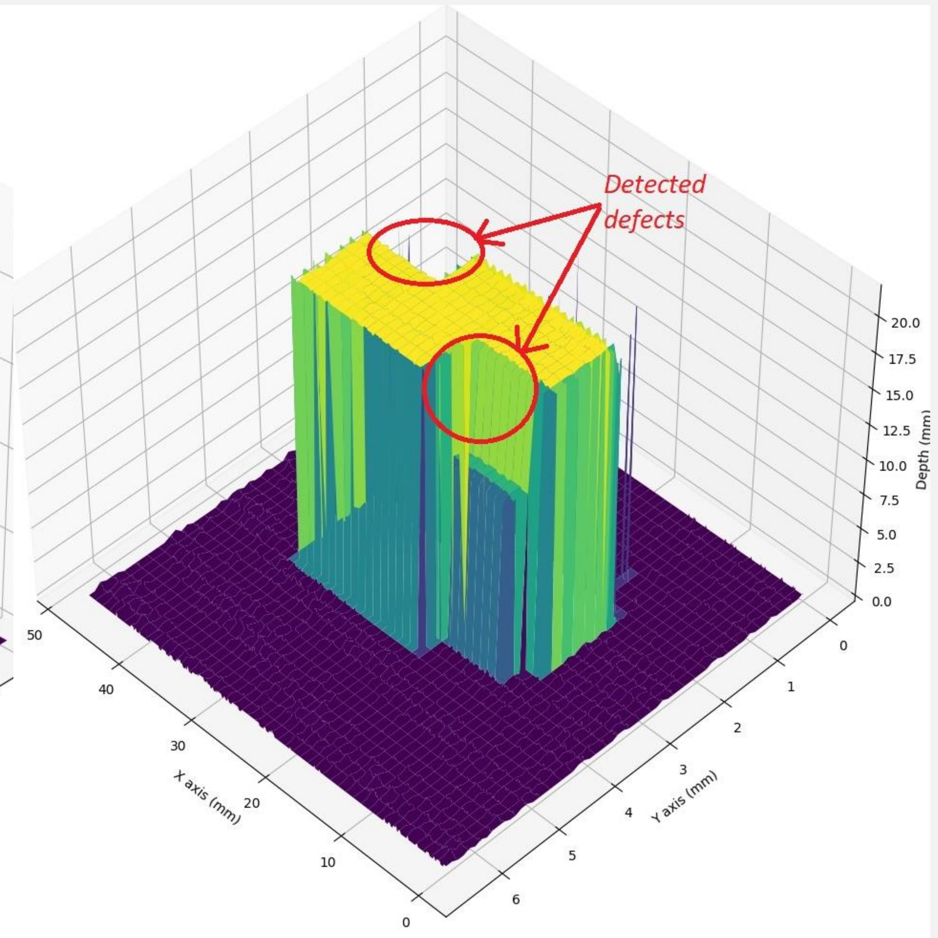


Fig 5: 3D reconstruction of defect test object

Discussion

- The errors were minimal, with the highest error percentage observed at 2.22% for a height of 2.35 mm. Notably, the error percentage decreased progressively as the height of the scanned objects increased. This also allowed object geometry reconstruct with acceptable accuracy.
- To evaluate the system's defect detection capability, deliberate flaws were incorporated into the CAD design of a 20 mm cube. The printed object, with these defects, was scanned using the system, and its geometry was generated. Visualization of the geometry revealed the presence of defects in the printed object.

Future Improvements

Advanced camera technologies, including higher resolution and multispectral imaging, improve accuracy and enhance edge detection and material differentiation. Enhanced data acquisition employs dynamic step sizes for complex areas and combines continuous video with high-resolution snapshots for comprehensive coverage. Real-time processing benefits from machine learning algorithms for edge detection and error correction, alongside parallel processing to speed up analysis and reduce computational load. Improved calibration involves automated procedures for precision and adapting to environmental changes like temperature and vibrations.

References

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