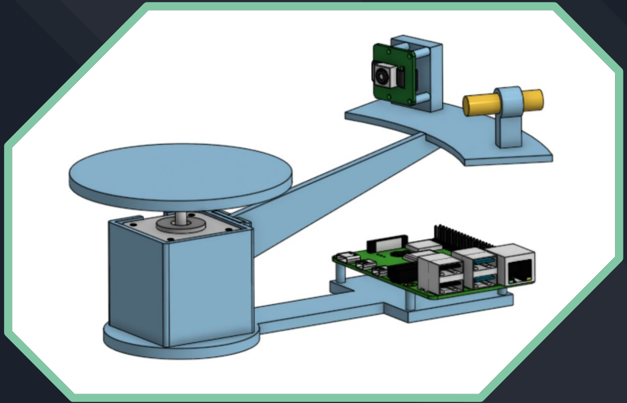
Low-Cost 3D Scanning Using Computer Vision and Triangulation



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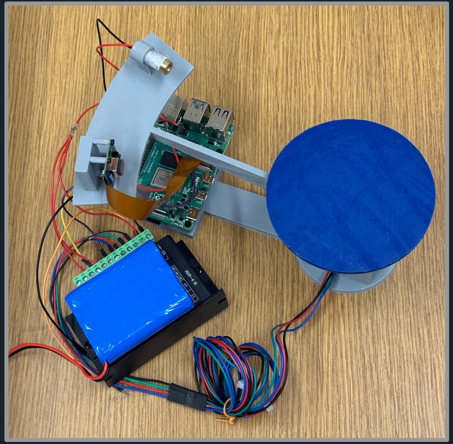
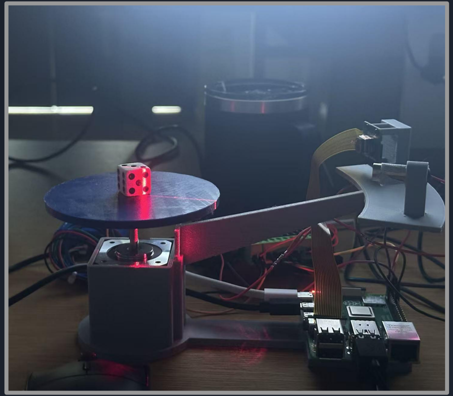
Project Overview

- A custom-built low-cost 3D scanning system that utilizes a camera, line laser, and rotating turntable
- Designed to capture object shape and geometry
- System is intended for small-scale objects
- Utilizes perspective based reconstruction with triangulation/filtering applied on the reconstruction for higher dimensional accuracy



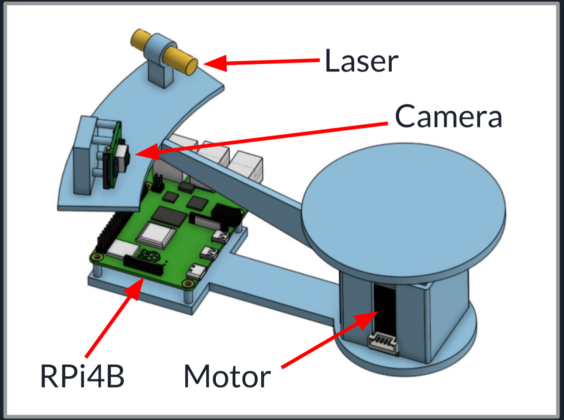


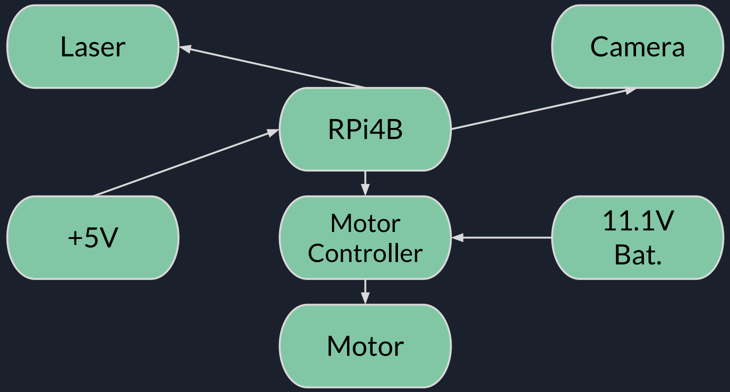
Motivation

- Most commercial 3D scanners are high-cost ($1,000-$100,000)
- Goal was to explore a low-cost and accessible design using open source software
  - OpenCV
  - Open3D
  - Meshlab
- Focused on understanding scanning and reconstruction principles
  - Thresholding
  - Perspective Scanning
  - Triangulation Scanning
  - Point Clouds
  - Remeshing

System Setup

- Raspberry Pi 4B controls image capture and motor rotation
- IMX519 camera captures high-resolution images
- Red line laser mounted at a known offset from the camera (angle and distance)
- Stepper motor rotates the object placed on the turntable with fixed step increments



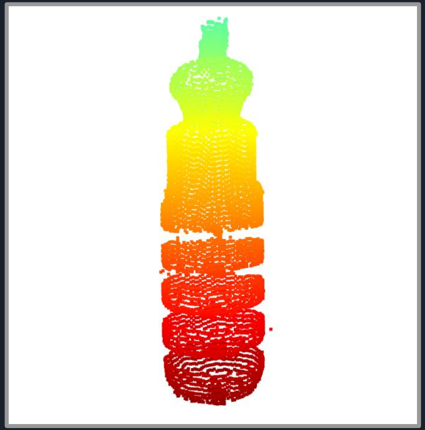


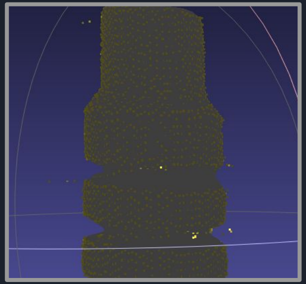
Scanning Approach (Perspective-Based)

- Originally, the camera views the scanning area at an angle
- A region of interest is chosen and the original view is transformed to display this region using OpenCV, removing unwanted image detail and image distortion
- The center of the new frame can be used as a reference point for each point created
- At this stage, a perspective-based 3D point cloud is generated by:
  - Laser line thresholding to isolate the laser projected on the object
  - (x, y, z) calculation of each laser point using the center of the frame as a reference point

Results

- Displayed is an example scan of an object point cloud with Open3D after one full rotation and the mesh reconstruction using Meshlab
- The object was chosen because of its cylindrical shape and surface detail
- Dimensions and scaling are currently inaccurate
- With additional rotations/scanning more surface detail is captured



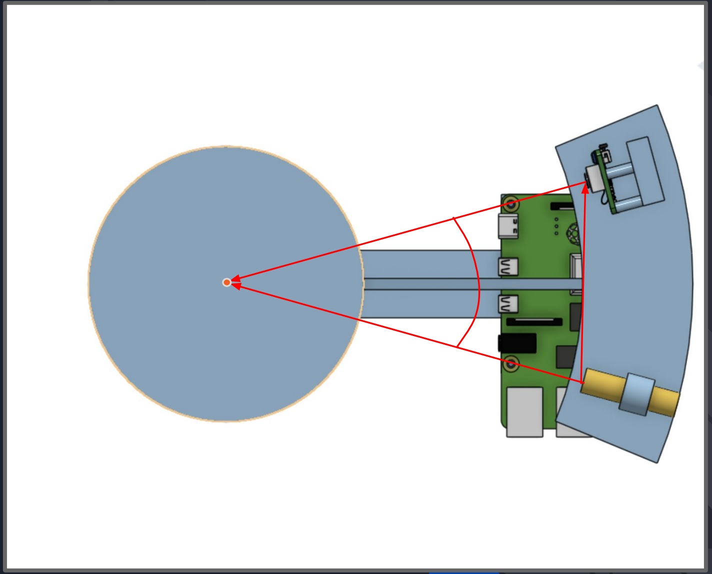


Limitations of Perspective-Based Reconstruction

- The perspective-based point cloud exists primarily in a camera-centric coordinate system
- The depth of each point comes from perspective effect in the image, not from true geometric measurement
- The overall shape and surface detail look correct, but the actual physical size is not matched
- As the object moves farther from the camera, the apparent scale of the reconstruction changes and must be adjusted using in-code parameters

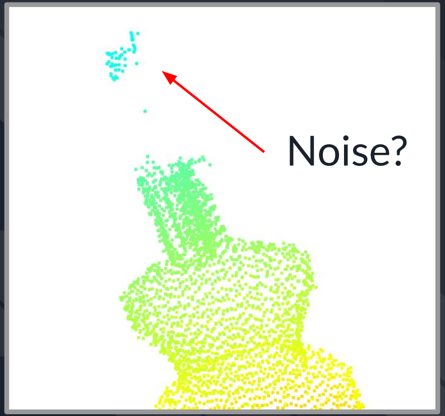
Triangulation-Based Reconstruction

- To account for inaccurate scaling from purely perspective based reconstruction, triangulation-based reconstruction was applied on the generated point cloud
- Triangulation uses the known geometric(distance, angle) relationship between the camera and the laser.
- For each detected laser point, its image position is used to calculate the point's depth in real space .
- This process converts the original perspective-based data into a point cloud with correct physical scale



Limitation of Triangulation

- Triangulation is sensitive to small errors introduced during image acquisition
- The camera uses an autofocus lens, and slight changes in lens position alter the effective camera geometry
- These variations increase error during triangulation and reduce reconstruction stability
- Using an unfixed camera exposure could lead to random points being generated
- As a result, some fine details visible in the perspective-based point cloud may be reduced or lost



Conclusion

- This project demonstrates a low-cost 3D scanning from image capture to 3D reconstruction
- Perspective-based scanning enables the capture of fine surface detail
- Laser triangulation applied on a perspective based scan provides meaningful size and spatial positioning
- The system highlights the trade-off between detail preservation and metric accuracy in low cost 3D scanning.