Measuring the Volume of Non-Uniform Objects Through Water Displacement

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Introduction

3D laser scanners and CMMs have difficulty accurately measuring volumes of parts with internal cavities, and relying on densities from material data sheets introduces further uncertainty. By using Archimedes' principle, we can quantify the water displaced by a submerged part, which we can relate to the true volume of complex, irregular shapes. Our project demonstrates this displacement method as a cost effective alternative for verifying volumes of cast manufactured components.

Methods

- Six measurements of volume and uncertainty for each calibration block and the pipe ID
- IR sensor (3D-printer calibrated) streamed distances to Arduino
- LabView recorded mean height difference and calculated volume
- Volumes verified by dividing mass by density

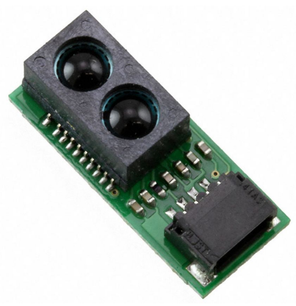

Figure 1: SHARP GP2Y0E02B Distance Sensor

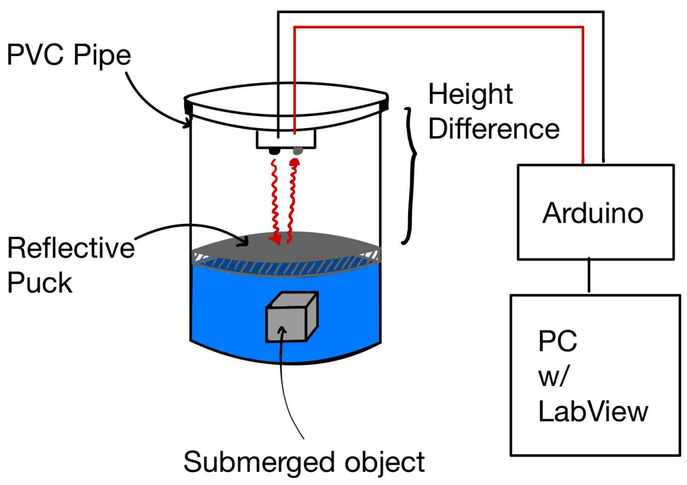

Figure 2: Hand sketch of experimental setup

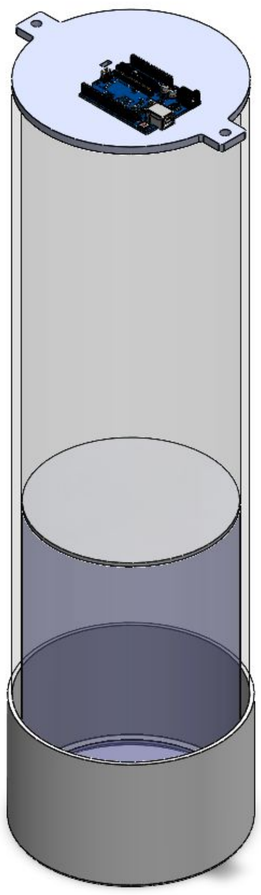

Figure 3: CAD model of experimental apparatus

Discussion

- From smallest to largest, caliper reference volumes are 117.44 ± 0.42 mL, 278.37 ± 0.44 mL, and 1024.02 ± 1.36 mL
- From smallest to largest, water-displacement gave 114.10 mL (2.85 %), 280.00 mL (0.71 %), and 947.64 mL (7.46 %)
- Large-block error stems from water clinging inside the PVC pipe during each drain–refill cycle
- Smaller blocks lose less water due to easier insertion and removal
- Uncertainty stems from IR-sensor random noise and systematic bias in distance readings, propagating into the calculated volumes

Results

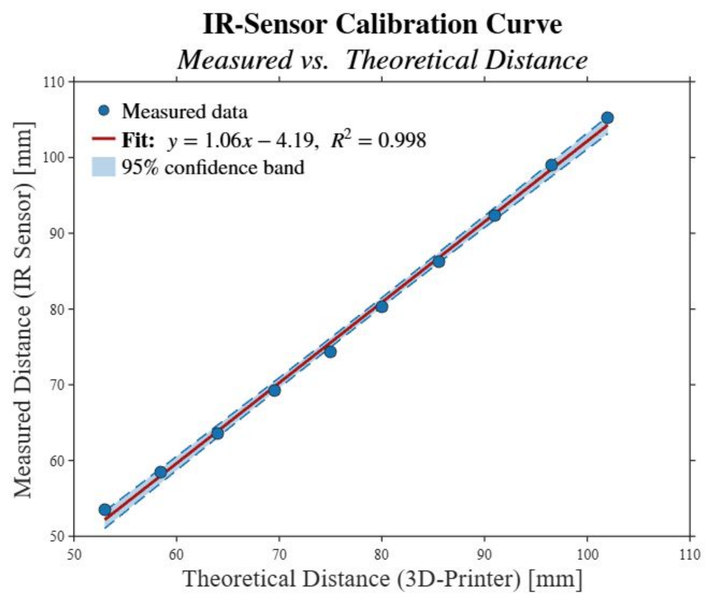

Figure 4: The 3D-printer calibration run confirmed that the GP2Y0E02B holds a ± 0.93 mm uncertainty between 50 mm and 100 mm.

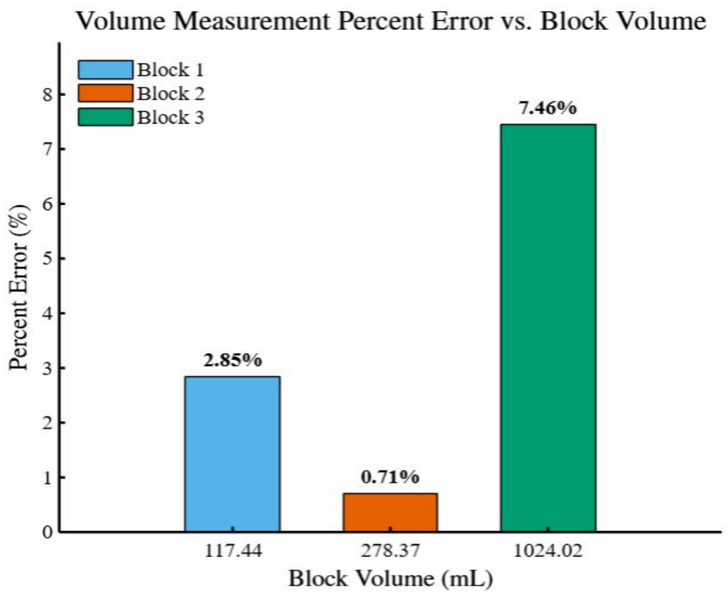

Figure 5: Error percentage plotted against the volume of the calibration blocks

Table 1: Comparative analysis of methods for measuring the volume (cost-to-accuracy)

Method	Cost ($)	Accuracy (mL)	C2A Ratio ($/mL)
Water Displacement	100	27.12	3.69
Mass-Density	325	36.30	8.95
CMMs	50000	1.74	28735.63

Conclusion

In theory, Archimedes' principle should be a quick and cost effective method of measuring volume, but in practice we have found this method to be riddled with sources of uncertainty. We would only recommend this method for a quick estimation. For porous, and absorbent materials, we expect the uncertainty to be even higher. Painting the inside of the PVC tube matte black can help cut down on IR-sensor noise, by suppressing stray reflections and improving the signal-to-noise ratio.

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