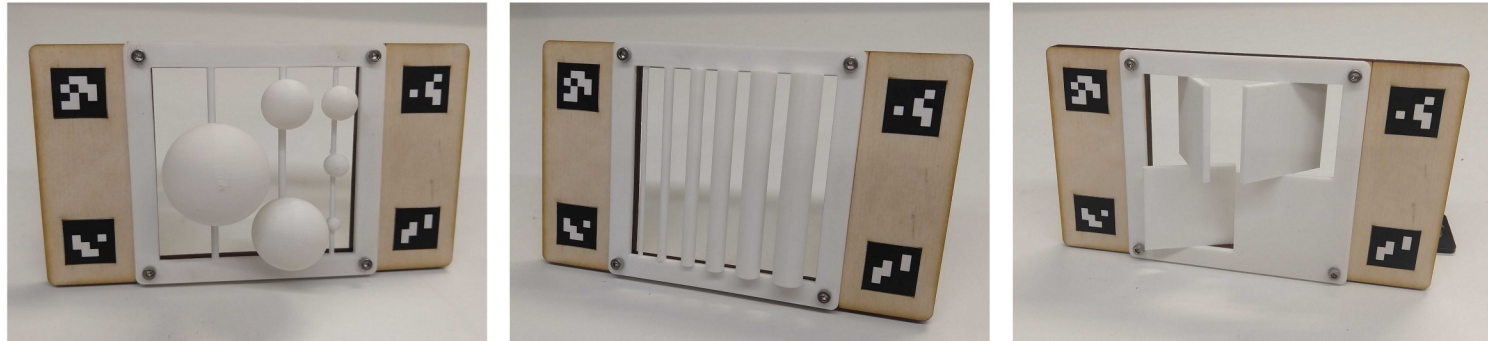


Depth Quality Assessment at Close Range Using 3D Printed Fixtures

github.com/root-ai/depth-quality

Michele Pratusевич
Director of Software





We use a set of **easily-produced 3D printed** and lasercut fixtures to measure depth quality. Simple geometries that approximate **real-world objects in manipulation environments** assess depth quality better than manufacturer metrics, which are often measured against flat walls. **Known fiducial locations** make the fixtures easy to align during processing.

ROOT AI AND ME



AGRICULTURAL ROBOTICS

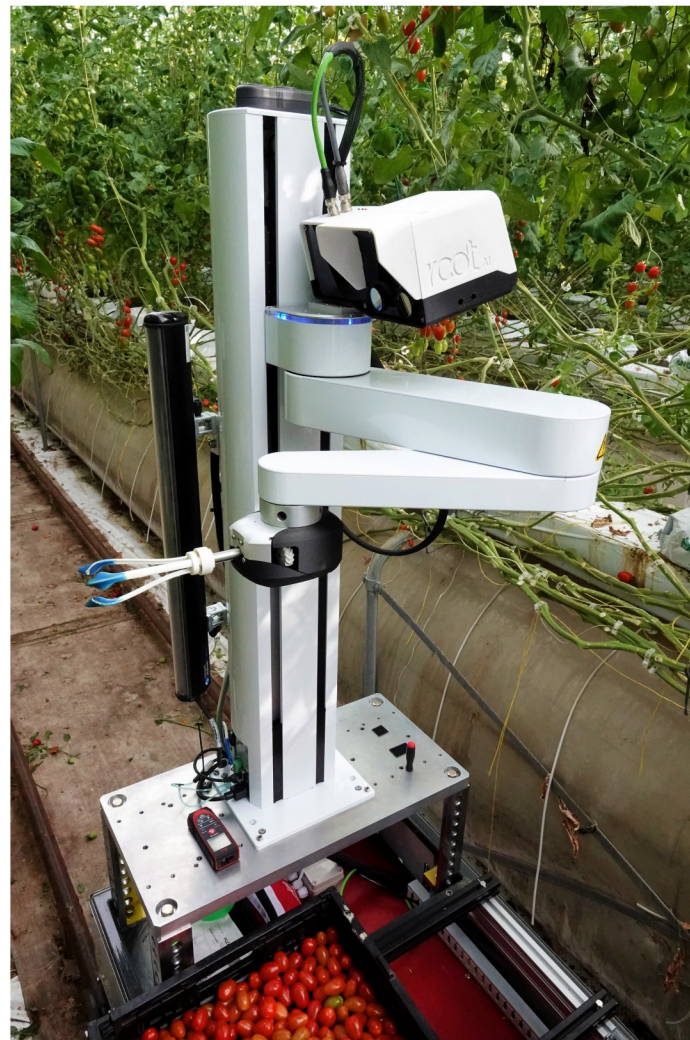


VIRGO THE HARVESTER



TOMATOES: **SMALL AND CLOSE**

To harvest, we need accurate representations in 3D. USDA provides **weight** (but not size) regulations so our information was gathered from customers. Cherry / grape tomatoes are about **20 mm** in diameter. Rows are narrow (~1 meter wide) so any manipulator needs to reach between 30cm and 70cm to harvest tomatoes. Need to select a good enough camera.



WHAT IS GOOD ENOUGH?

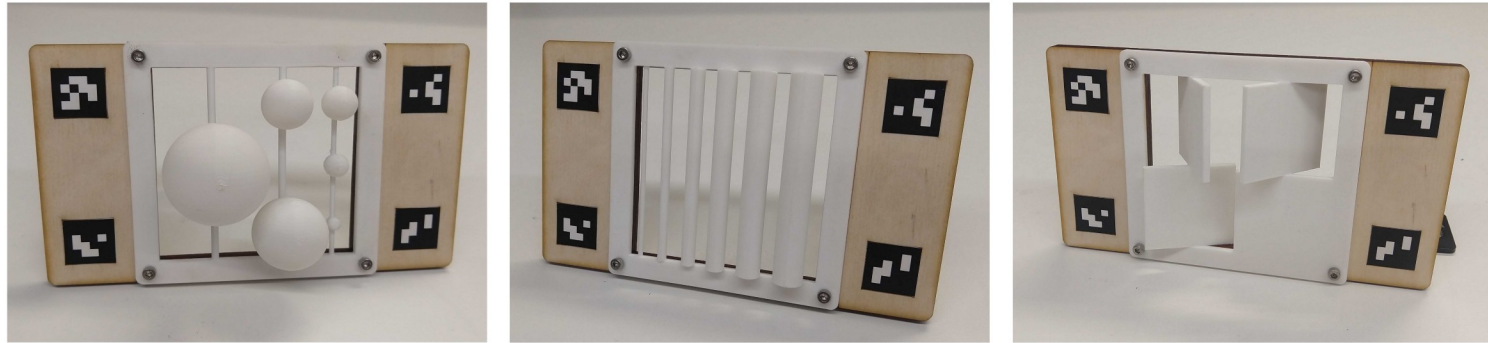
Intel Realsense publishes their testing methodology (RMSE of a white wall). Other manufacturers (ZED, Asus) don't.



https://www.intel.com/content/dam/support/us/en/documents/emerging-technologies/intel-realsense-technology/RealSense_DepthQualityTesting.pdf

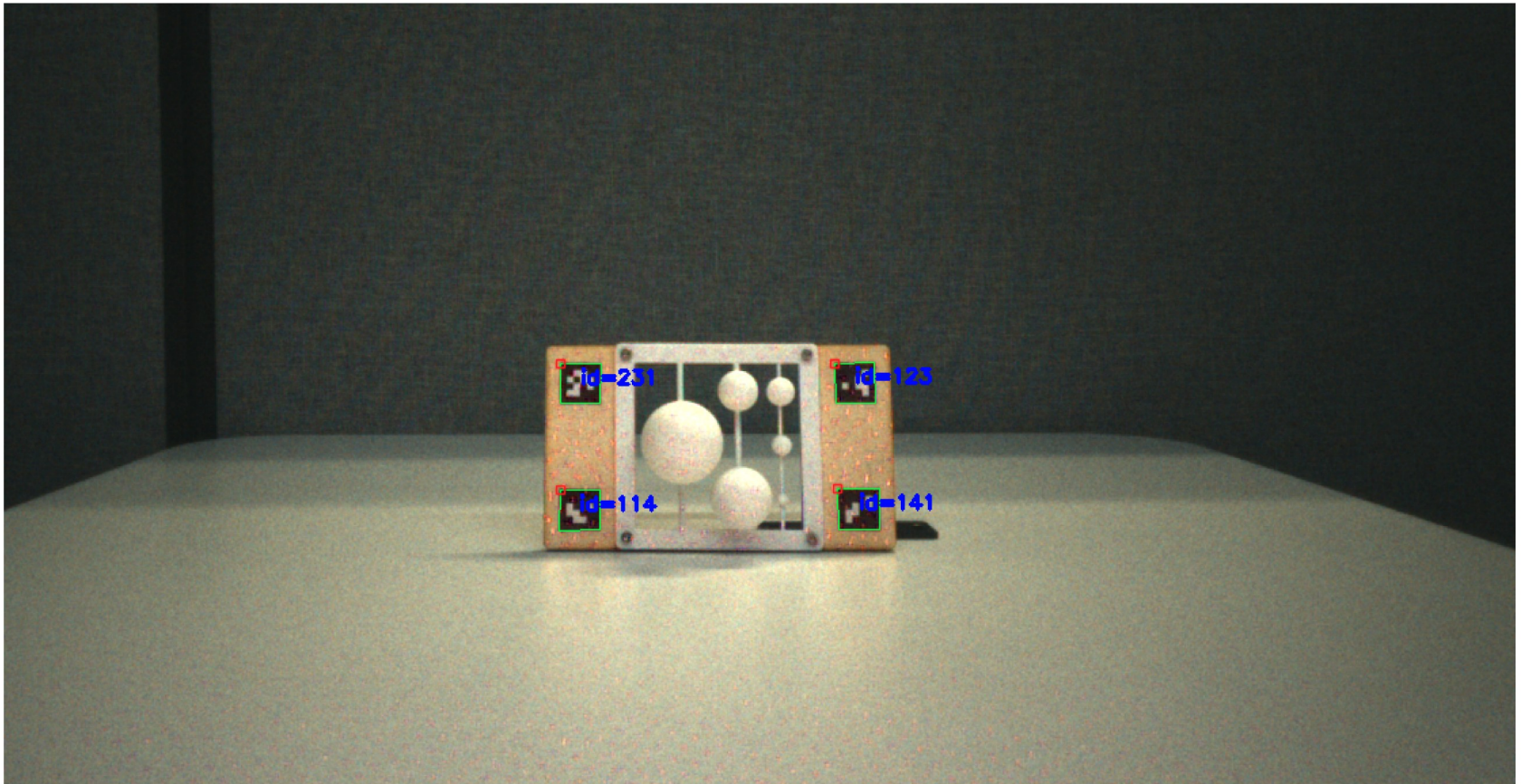


RMSE on a white wall does not approximate our complex scene.



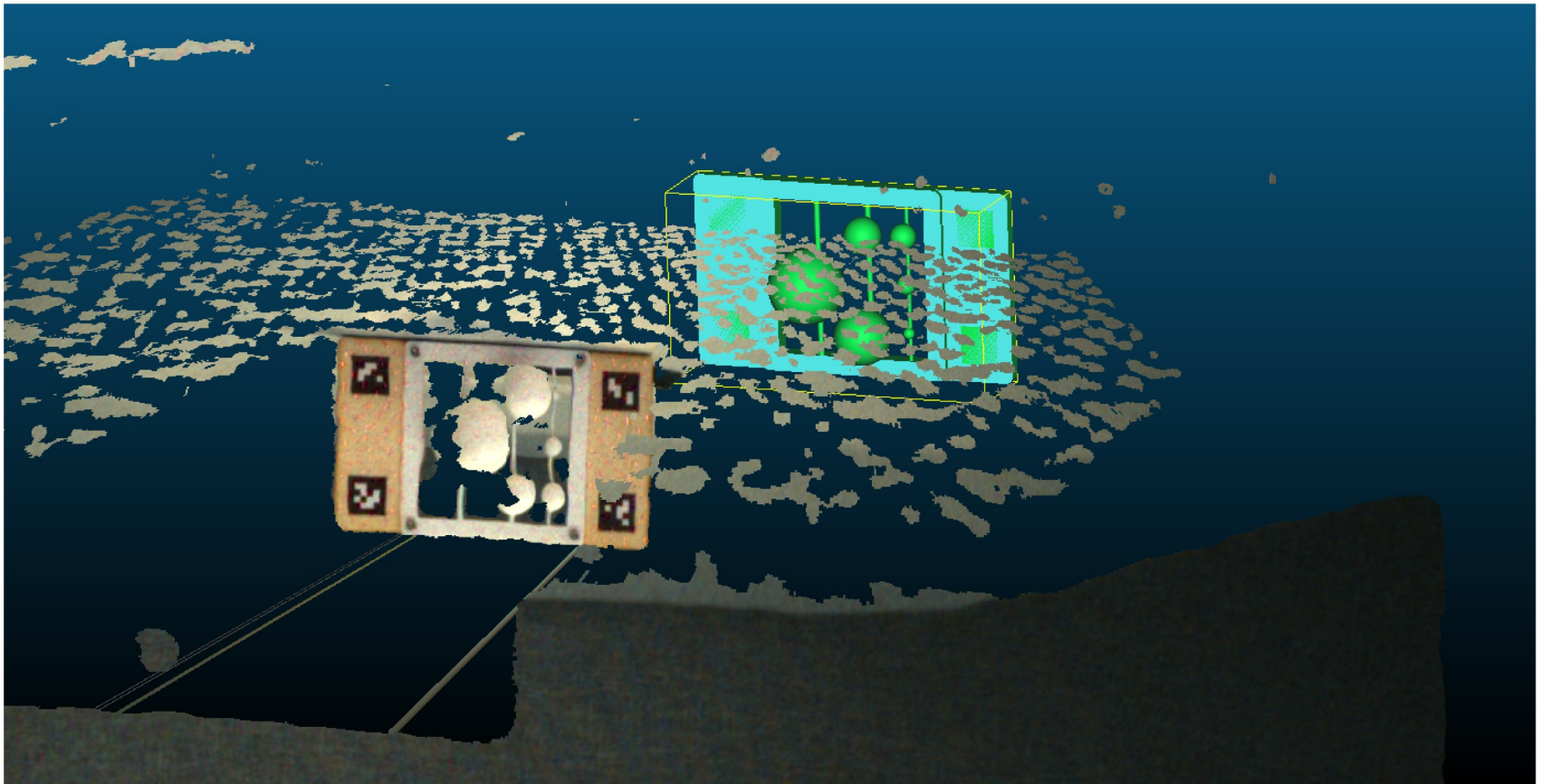
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EVALUATION STEP 1



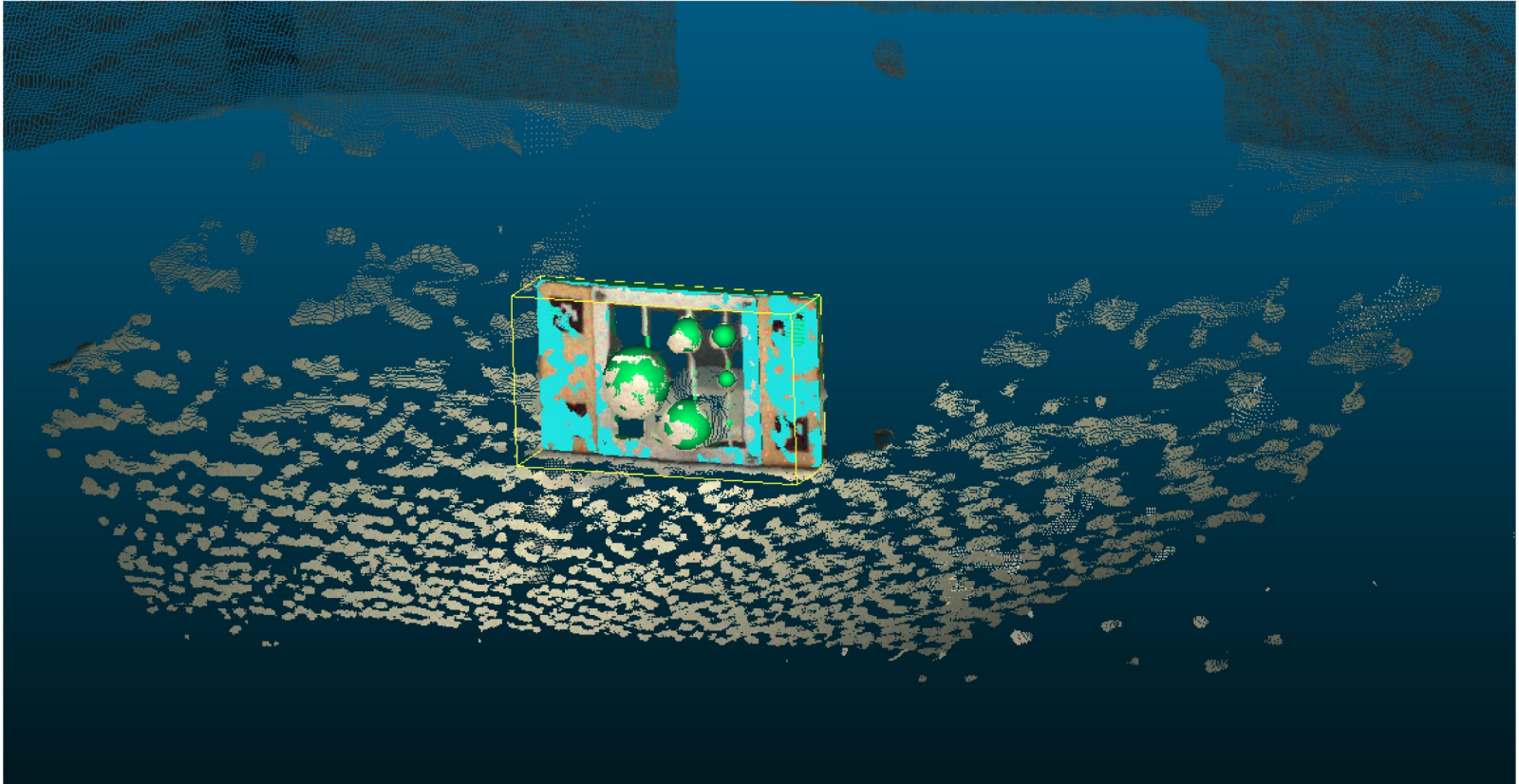
Capture RGB image and detect fiducials

EVALUATION STEP 2



Capture pointcloud

EVALUATION STEP 3



Align pointcloud to 3D model, crop, and evaluate

RMSE of pixels in the test object segment (and not anywhere else).

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (o_i - e_i)^2}$$

Density of points that are on surfaces the camera should see.

$$\text{Density} = \frac{1}{A} \sum_{i=1}^n \begin{cases} 1 & \text{if } |o_i - e_i| < t \\ 0 & \text{otherwise} \end{cases}$$

$$A = \sum_{f \in \text{faces}} \begin{cases} \text{Area}(f) & \text{if } \arccos(f_{\perp} \cdot c) > \frac{\pi}{2} \\ 0 & \text{otherwise} \end{cases}$$

CAMERA SELECTION

RMSE (m) AND DENSITY (PIXELS / m^2) FOR 3 CANDIDATE CAMERAS

Fixture	Metric	D415	D435	ZED Mini
Cylinders	RMSE	0.00177	0.00200	0.00319
	Density	0.00144	0.00137	0.00197
Spheres	RMSE	0.00269	0.00415	0.00532
	Density	0.00150	0.00098	0.00182
Angled plates	RMSE	0.00223	0.00286	0.00324
	Density	0.00145	0.00140	0.00223

For our application, the **D415** gives the best accuracy.

SANITY CHECK

When the target is farther from the camera, the RSME is higher and the density is lower. The target was aligned as close to the center of the FOV as possible.

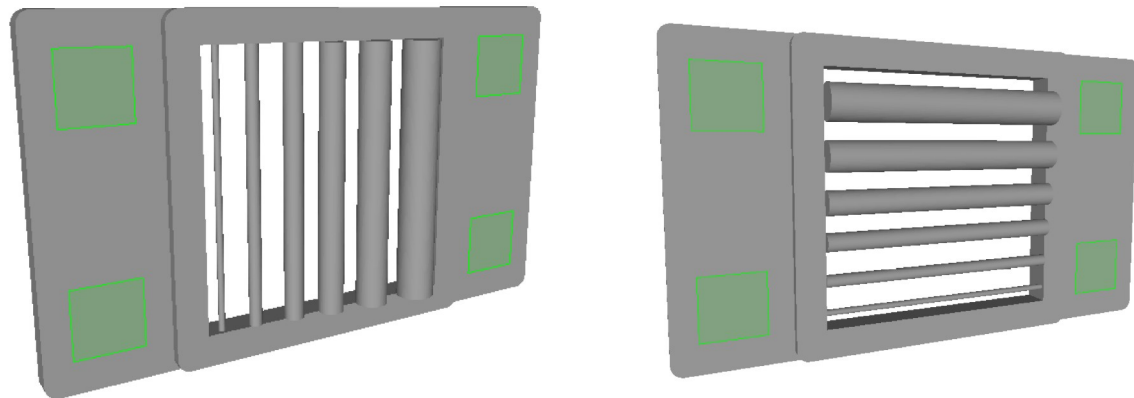
RMSE (m) AND DENSITY (PIXELS / m^2) FOR D415 WITH CYLINDERS AT VARIOUS DISTANCES (INCHES)

Distance	RMSE	Density
16	1.64	3.36
20	1.97	1.61
24	1.76	1.44
28	2.18	0.91
32	1.97	0.79
36	1.89	0.61
40	2.05	0.48

USES AND EXTENSIONS

3D printing targets makes creating standard targets easy to reproduce. More work is needed to determine optimal materials, settings, etc. Can create targets specific to different characteristics:

- Shapes
- Sizes
- Surface colors / textures
- Specularity



LEARN MORE

- Github: <http://github.com/root-ai/depth-quality>
- More about Root AI: <http://root-ai.com>
- Email me: mprat@root-ai.com
- Paper on ArXiv:

