

INVESTIGATING THE FACTORS THAT INFLUENCE 3D STEREO DEPTH SENSOR NOISE

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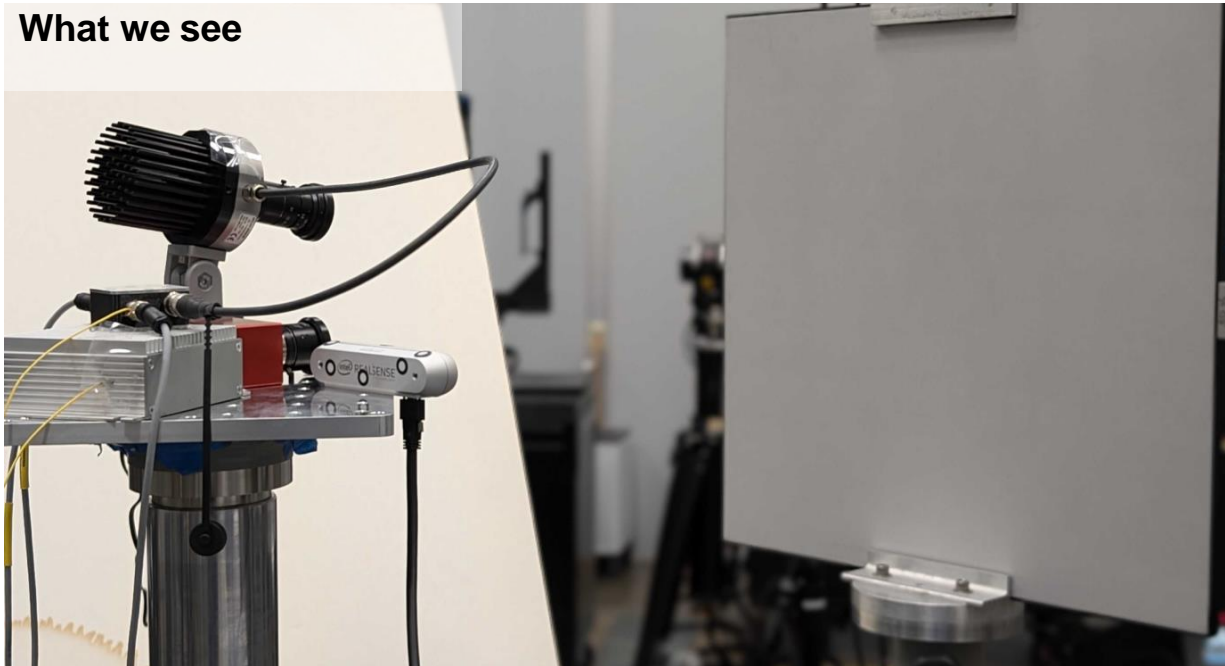
Intelligent Systems Division
Engineering Laboratory

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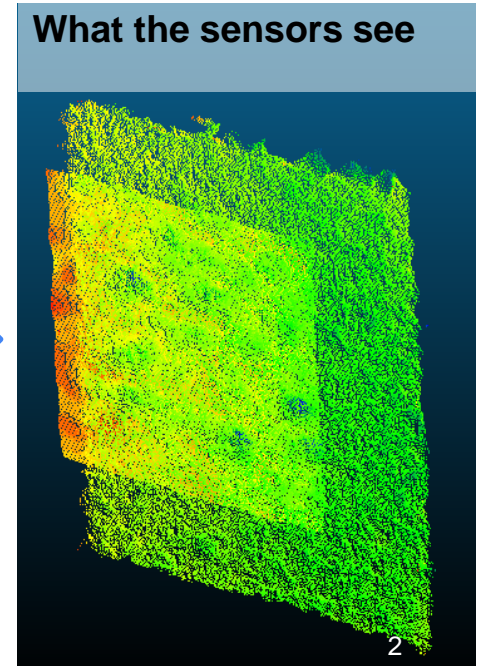
What are Stereo Depth Sensors

- Obtains 3D point cloud data of surfaces
- Uses 2 cameras to obtain depth information

What we see



What the sensors see

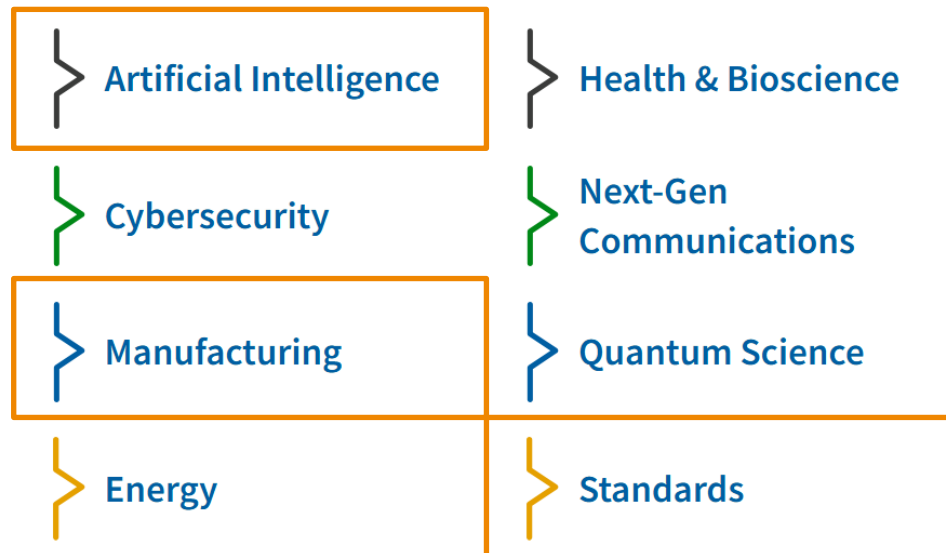


Overarching Objective

NIST aims to:

- develop standards for these sensors
 - characterizing noise helps develop metrics and standards
- investigate the state of current commercial technology
 - *Not* targeted any specific sensors

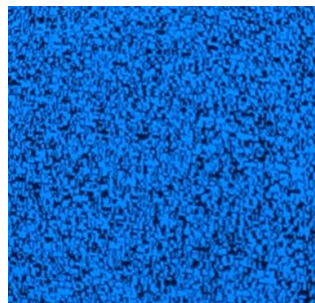
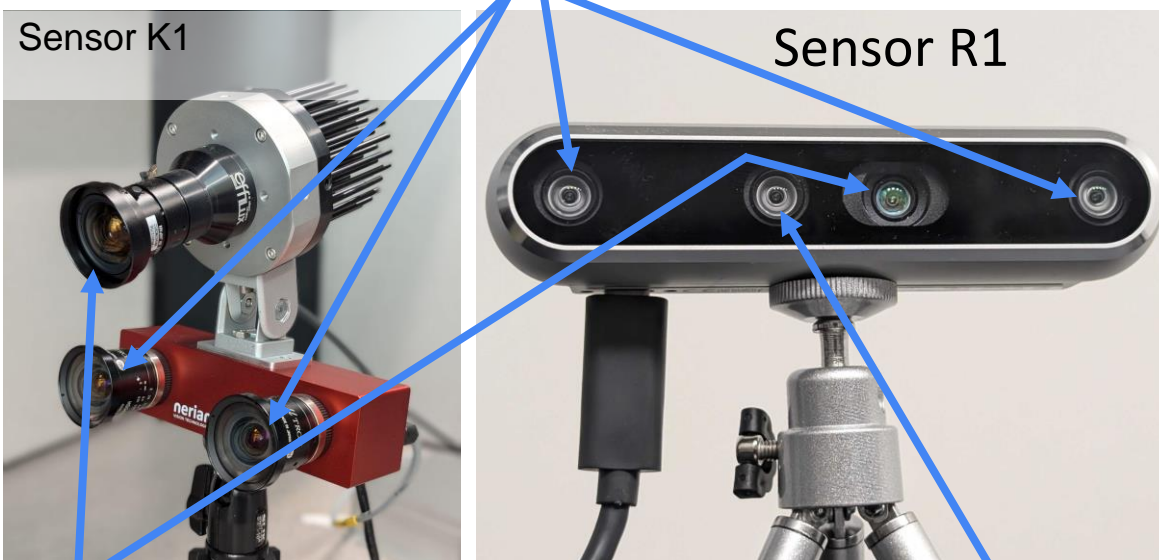
Examples of sectors
NIST aims to help:



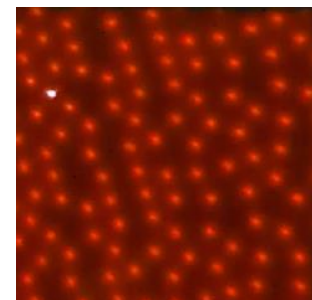
Project Objective

Understand the parameters that affect the noise of 3D sensors and quantify them.

Stereo Depth Imagers



K1's dot pattern
(visible spectrum)

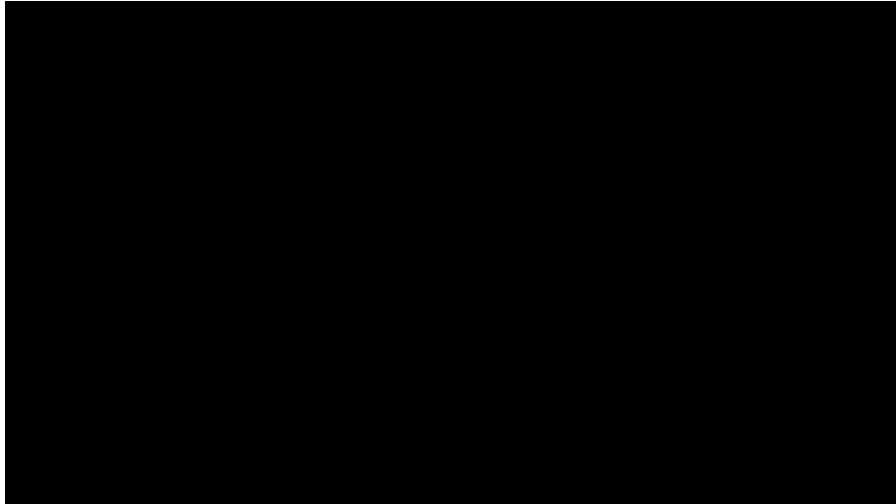


R1's dot pattern (\approx
850 nm)

Projector

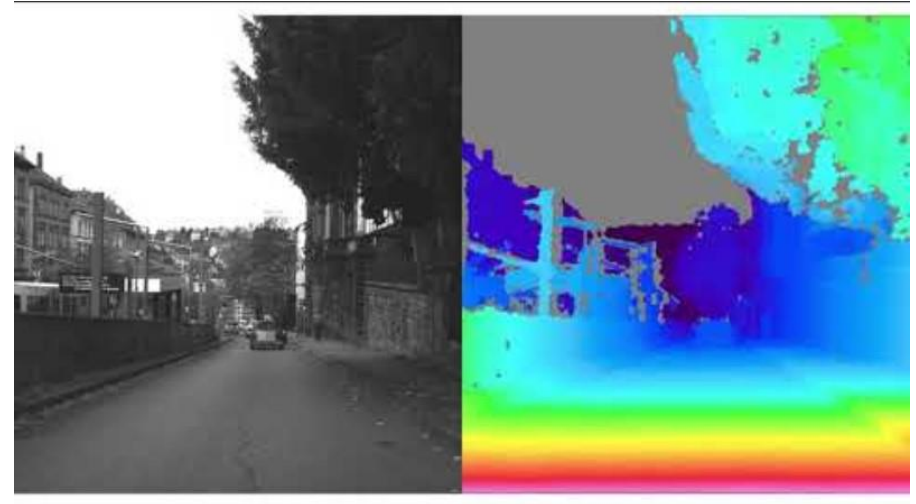
RGB Camera

Object Picking



Source: https://www.youtube.com/watch?v=_MWmCAAdCD3o&t=10s

Autonomous Driving (Using K1)



Source: <https://www.youtube.com/watch?v=r0pECtAApzi>

Why does this study matter?

- Sensor noise affects parameters derived from the 3D point cloud data and/or 2D depth images which for example can affect:
 - 6 DOF pose determination (position and orientation)
 - Throughput times in a bin-picking application
 - Ability to resolve features
- Machine learning (ML)
 - Applying 2D Image-based ML algorithms to depth images is becoming more common
 - Can use the cameras on the devices for general image ML models

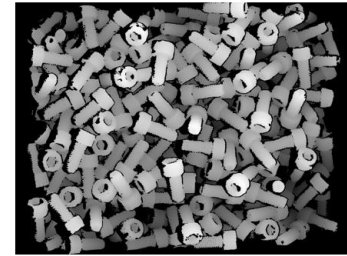
RGB image from a 3D sensor Z1



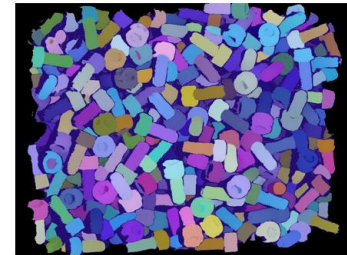
Output of AI/ML model to detect individual objects from RGB images



Depth image from a 3D sensor Z1



Output of AI/ML model to detect individual objects from depth images



Source: NIST

Sensor Specifications

- Cropped the region of interest (ROI) to 200 pixels × 202 pixels
- All trials were done with a fixed aperture

Sensor model	Technology	Frames per second	Light source Wavelength	Depth Image Pixel Resolution**	Depth Working Range
K1	Active* Stereo	28-32 (up to 54)	≈ 465nm	1024 × 768	0.23m - 100m
R1	Active* Stereo	30 (up to 90)	≈ 850nm	848 × 480	0.3m - 3m
R2	Active* Stereo	30 (up to 90)	≈ 850nm	848 × 480	0.6m - 6m

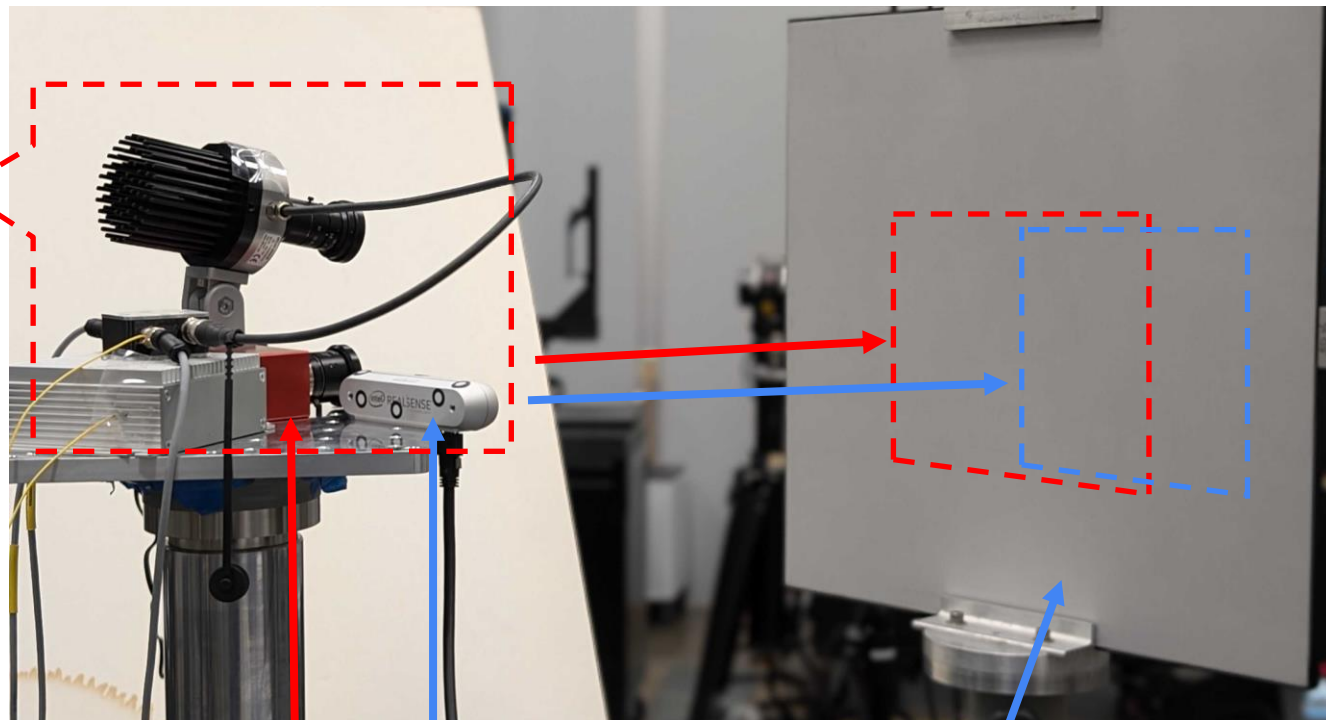
* Mode can be switched to passive when the emitter/projector is off

** Resolution can be further adjusted but these were the settings used for experimentation

Experimental Setup



Light meter

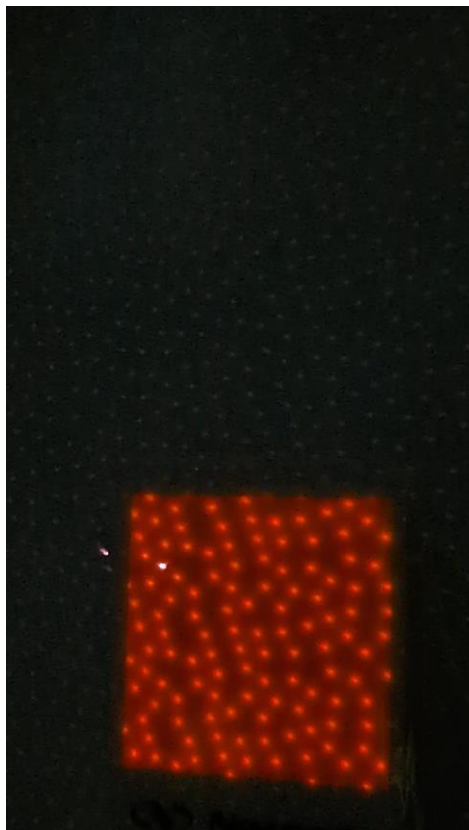


K1

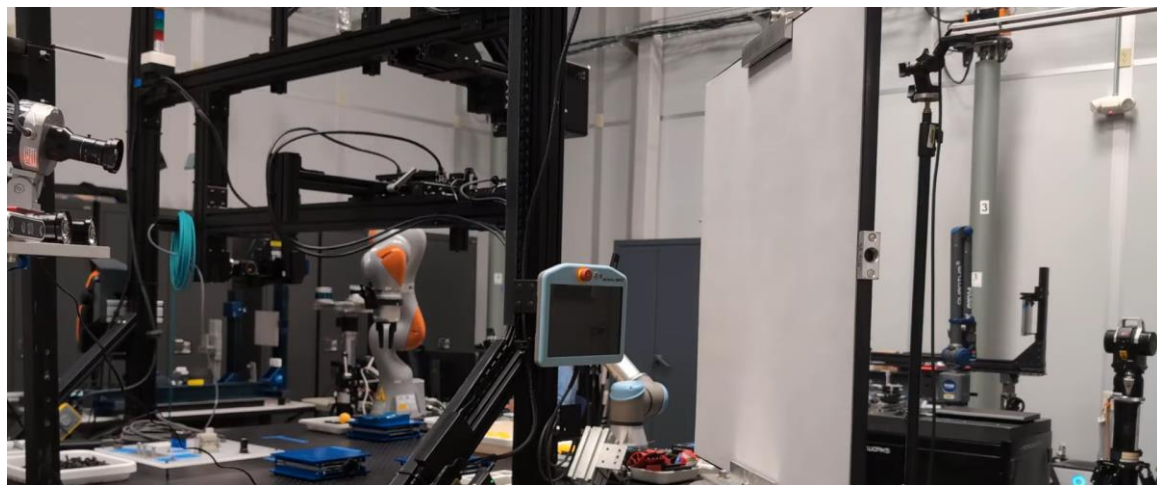
R2

Lambertian target
(50% reflectance,
0.61 m x 0.61 m)

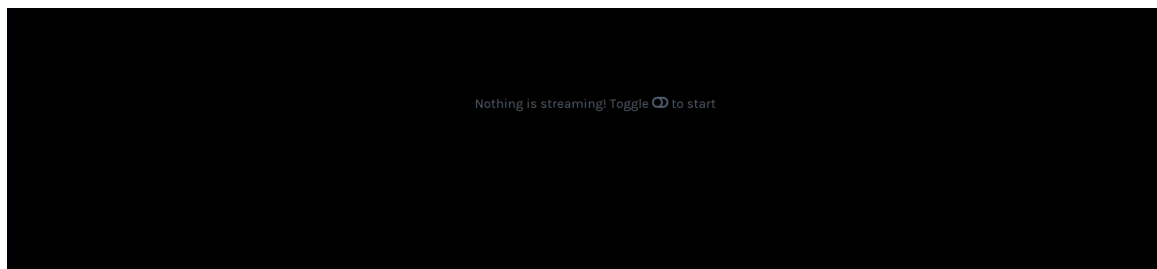
Experimental Setup and Demonstration



R2 IR Pattern



K1 projector switching on before the scan



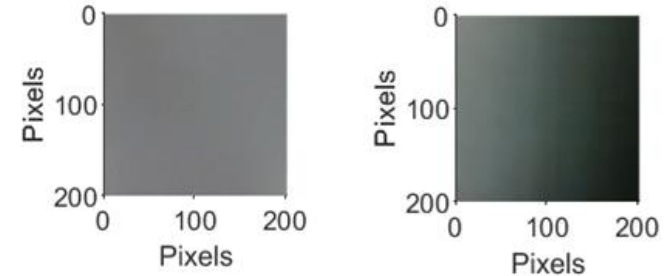
R1 and R2 Data Example

- **Types of startup and Transients**
 - Does it matter if the sensor is restarted a lot while in operation? If so, which method is preferred?
- **Sensor settings**
 - How do different sensor settings affect the noise?
- **Target Material**
 - How does the target's reflectivity, color, etc. affect the sensor's accuracy?
- **Environment**
 - How does the ambient light affect the accuracy?

Note: Typical illuminance values of 120-160 Lux when measured normal to the target



RGB Images of White and Gradient Targets



The white region of the target when captured by the sensor appears gray. This is due to low ambient light and sensor settings

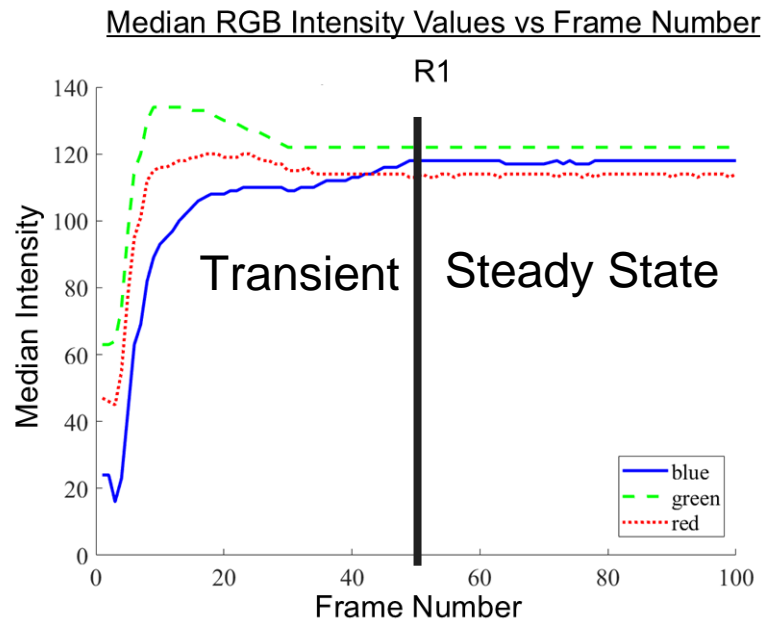
Transient (time-dependent) Effects on RGB Image Intensity Values

R1: Transient Effects (2D RGB image)

- In RGB, we see it can take around 52-65 frames (@30 fps) for a steady image to be reached
- Different results from depth data

Why does this matter?

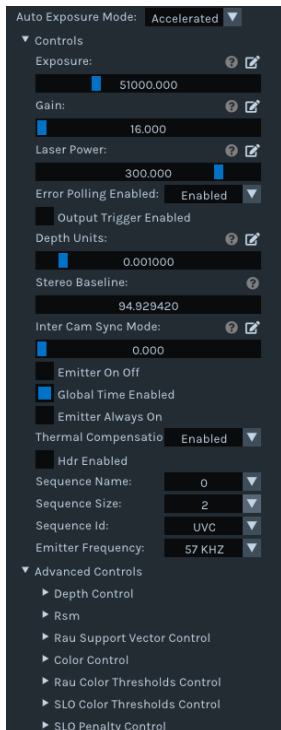
- If applications are using ML algorithms it is crucial they are aware that images at the start are not accurate



Study of some parameters that affect sensor depth quality

Available sensor settings

- Lots of settings to choose from, need to narrow it down



R1

Simple Camera Settings (Both Cameras)

Analog Control

Black Level:  5.86 %

Acquisition Control

Trigger Selector:

Trigger Mode:

Trigger Source:

Trigger Activation:

Image Format Control

Pixel Format:

Width:  320

Height:  336

Binning Horizontal:  2

Binning Vertical:  2

Decimation Horizontal: 1

Decimation Vertical:  1

K1

Available sensor settings

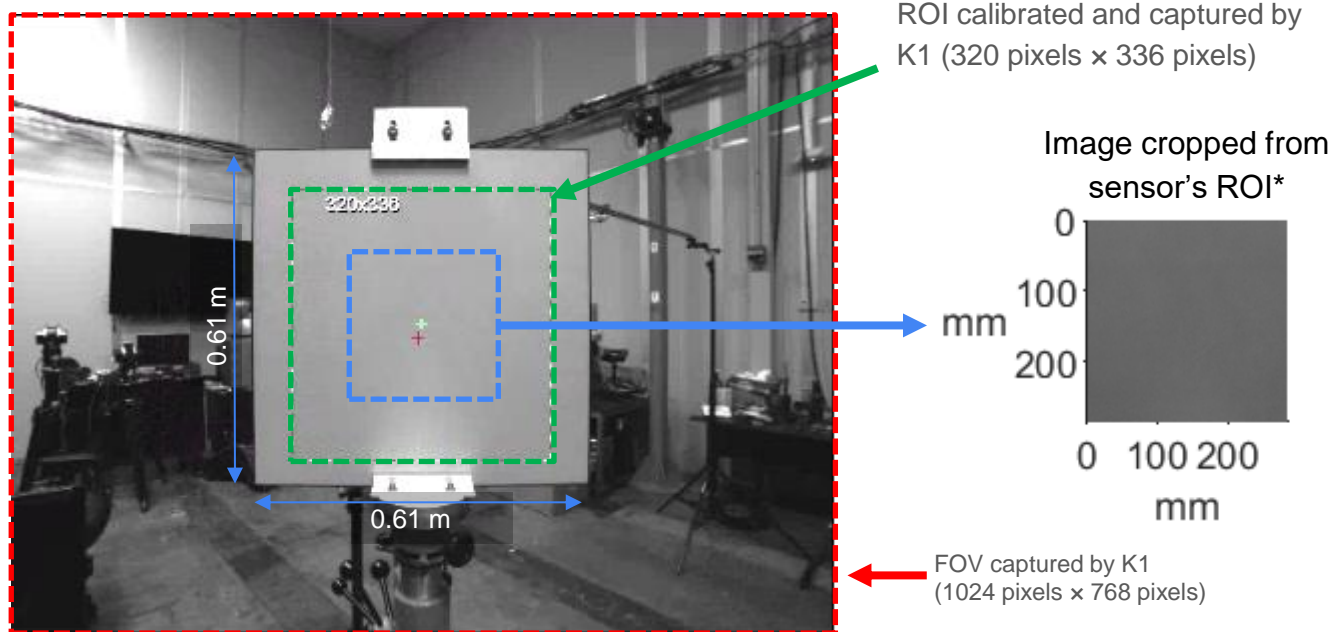
#	R1 and R2	K1	Explanation
1	emitter_enabled	trigger_1_enabled	Boolean/Turn the emitter on/off
2	enable_auto_exposure*	auto_exposure_mode	Boolean/Changes the settings from automatically set to manual
3	exposure	manual_exposure_time	Adjusts the exposure
4	gain*	manual_gain	Adjusts the gain
5	laser_power	trigger_1_pulse_width	Adjusts the strength of the active mode in different ways

- The number of parameters was reduced down to three: Exposure, Gain, Laser Power
 - There are several parameters for R1, R2, and K1, but these were the parameters that were most analogous between these two sensors.

* Can't change it programmatically. This needs to be set manually in the sensor software

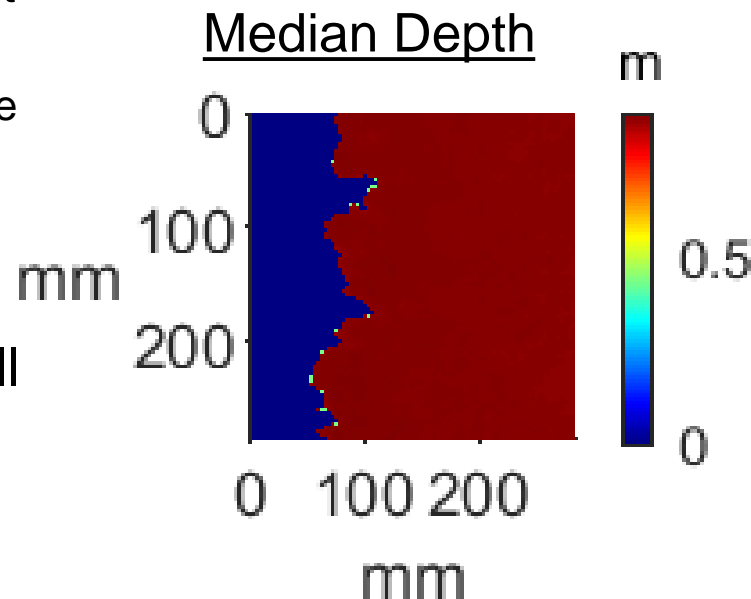
K1 Field of View and Calibration Region

- K1's calibration process relies on more manual work from the user per environment
- In contrast, R1 self-adjusts and less manual calibration is needed



K1: Zero depth data on one side

- K1 exhibited no data (zero depth) to the left of the imaged region.
 - The sensor manufacturer was contacted, and the recommendation was to calibrate the sensor.
 - The sensor was calibrated with a reprojection error of 0.087 pixels, but this was unresolved.
- Allowed us to study the parameters that will improve data quality and data “coverage” on the target.

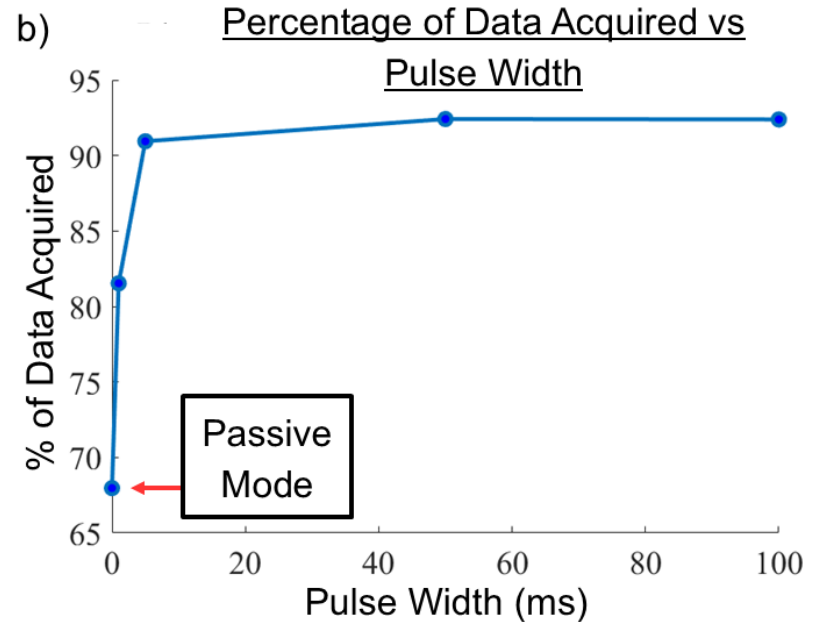
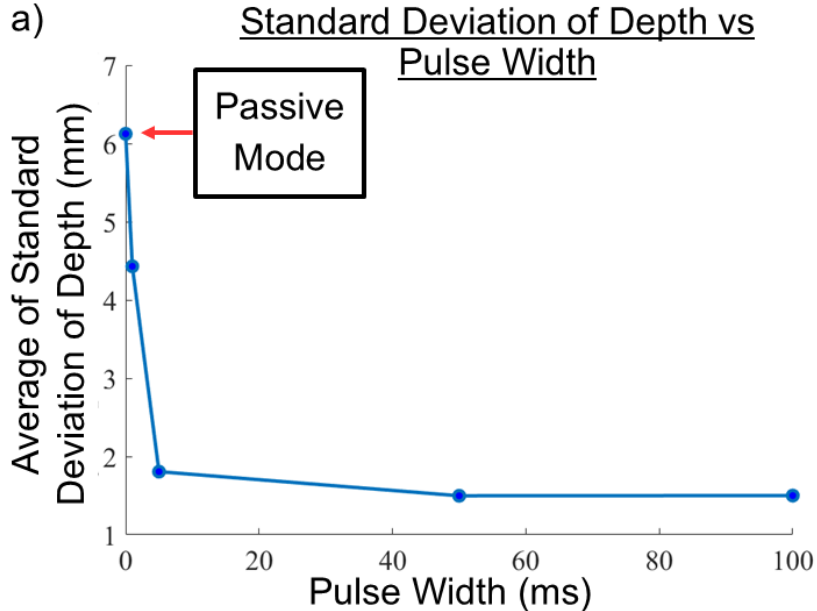


K1: Varying Pulse Width Settings

Higher Pulse Width values result in:

- Lower Noise (Standard Deviation)
- Higher percentage of data acquired

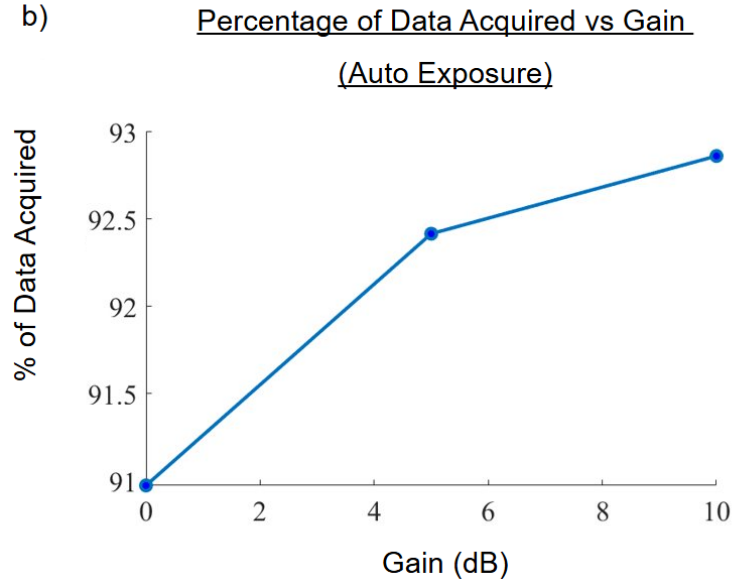
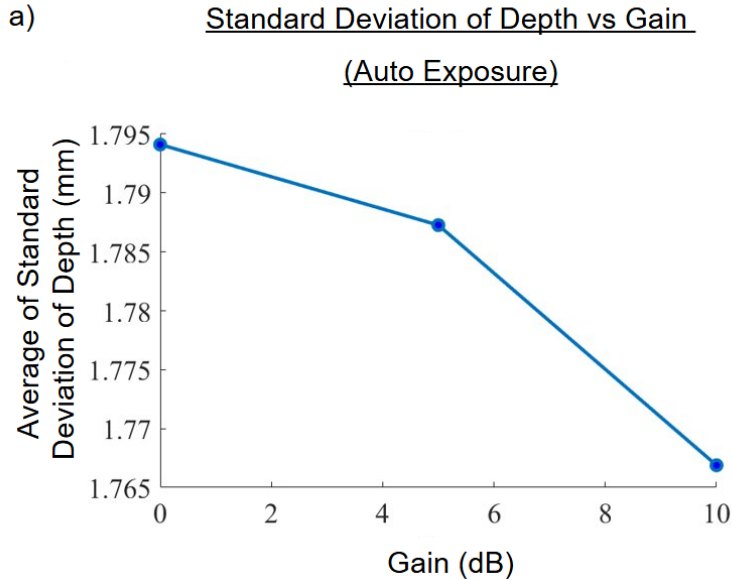
K1 settings: Auto-gain and auto exposure



*When Pulse Width is 0, sensor is in passive mode

K1: Two available auto-settings are not optimal

- As expected, higher gain means less noise and more data acquired
- Notably, when both auto exposure and auto gain is on
 - Higher Standard Deviation (noise): 1.806 mm
 - Lower percentage of data acquired: 90.94%



Conclusion

- We observe major transient effects across 2D images from the R1 sensor.
- Laser/projector/emitter settings can be optimized beyond the auto-settings suitable for a particular environment.

Thank you very much for listening!

Any Questions?

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