FOR ENERGY EFFICIENT INNOVATIONS

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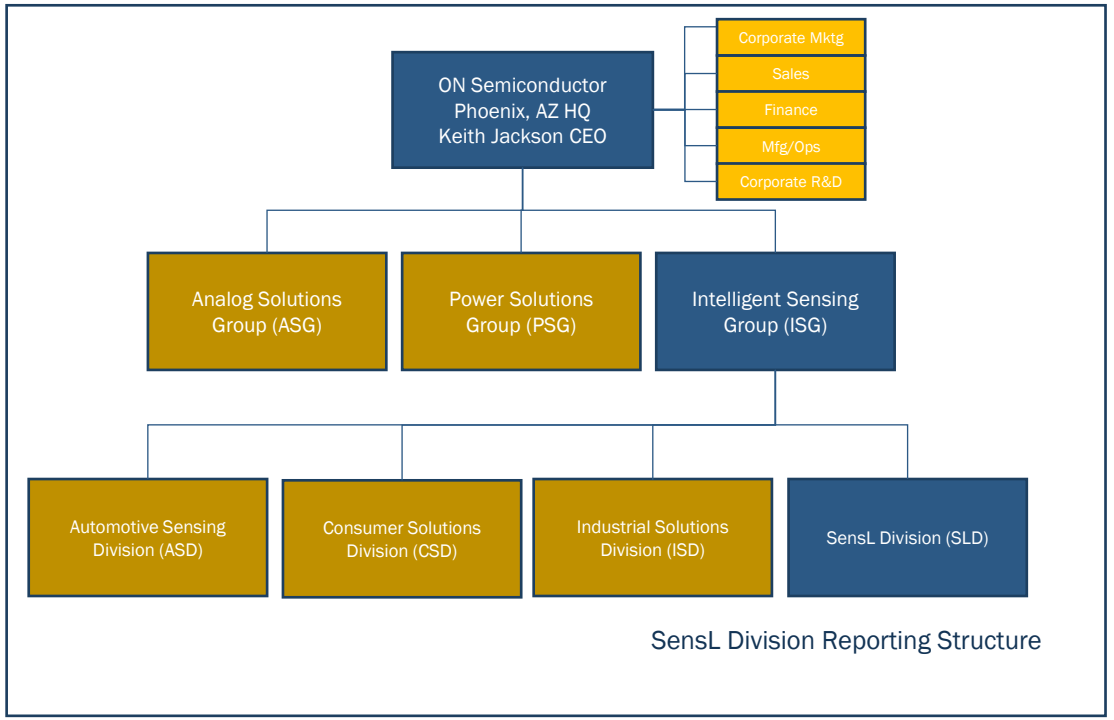
Depth and Intensity LiDAR imaging with Pandion SPAD array

International SPAD Sensor Workshop 2020

Public Information

SensL Division (SLD) of ISG

- SensL acquired by ON Semiconductor May 2018
- Independent division within Intelligent Sensing Group (ISG) focused on LiDAR solutions
- Division engineering remains in Cork Ireland
- Leveraging resources of all 34,000 ON employees



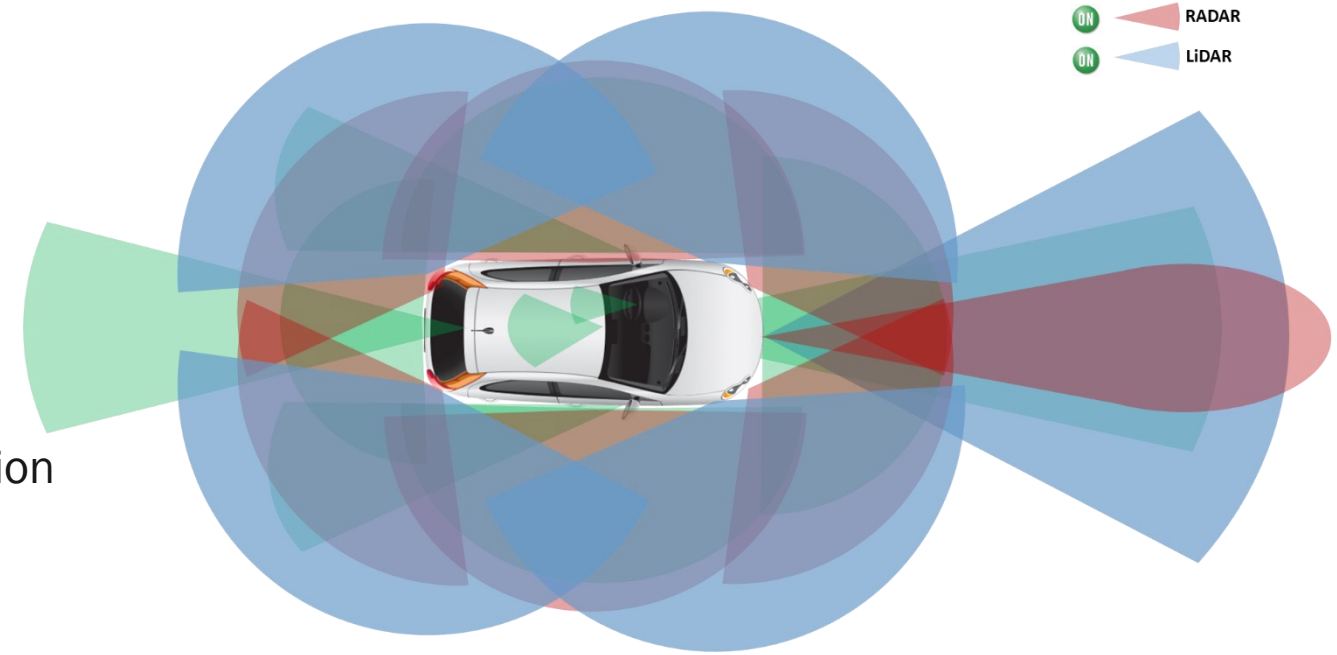
SensL Division Reporting Structure


World HQ
Phoenix, AZ USA


ISG HQ
Santa Clara, CA USA


SensL Division HQ
Cork, Ireland

ADAS/AD: A Fusion of Sensors



- Definition:
  - Provide color/intensity, depth, velocity for every point/kernel in scene in all conditions
- Benefit:
  - Drive higher confidence decisions from perception algorithm through redundancy and existence of multiple modalities with unique advantages

- *"Sensor fusion is key because the more complex features get, the more redundancy you need. Every autonomous vehicle is going to have some combination of LiDAR, Radar and camera."*

  - ADAS engineer at prominent OEM, Beyond the headlights: Woodside Capital Partners

- ISO26262 ASIL D means that a backup system must be ready to take over in case of system failure
- ASIL D system rating means higher complexity due to the safety requirements.
  - ASIL levels are often decomposed to lower ratings for the components (e,g. ASIL B in an ASIL D system)

Sensor Performance Comparison

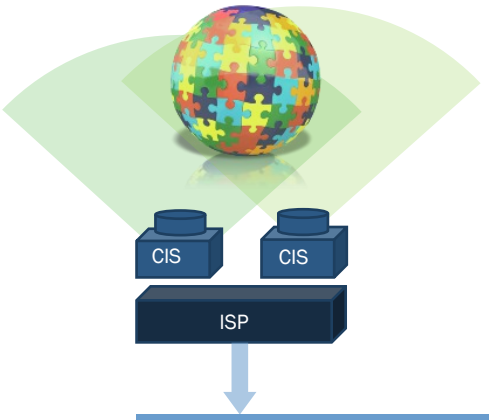
	IMAGING 	RADAR 	LIDAR 	ULTRASONIC 
Angular Resolution	🟢	🟡	🟢	🔴
Depth Resolution	🟡	🟢	🟢	🟢
Velocity	🔴	🟢	🟡	🔴
Depth Range	🟡	🟢	🟢	🟡
Traffic Signs	🟢	🔴	🟡	🔴
Object Edge Precision	🟢	🔴	🟢	🟡
Lane Detection	🟢	🔴	🟡	🔴
Color Recognition	🟢	🔴	🔴	🔴
Adverse Weather	🟡	🟢	🟡	🟢
Low-Light Performance	🟡	🟢	🟢	🟢
Cost	🟢	🟢	🟡	🟢

Sensor Fusion for ADAS/AD

Depth Mapping – Techniques – Time of Flight

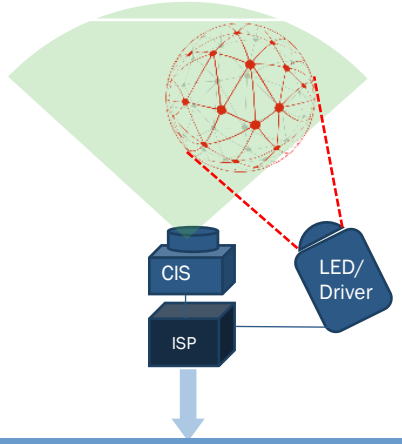
Stereoscopic Vision

Dual camera monitoring Image offset to measure the distance of the target



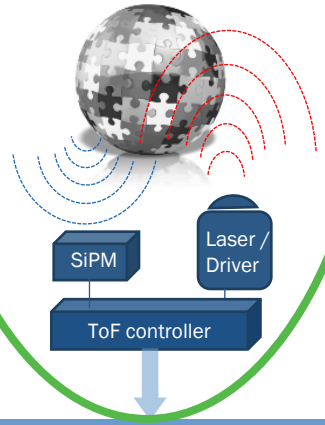
Structured Light

Single camera monitoring distortion from IR light pattern



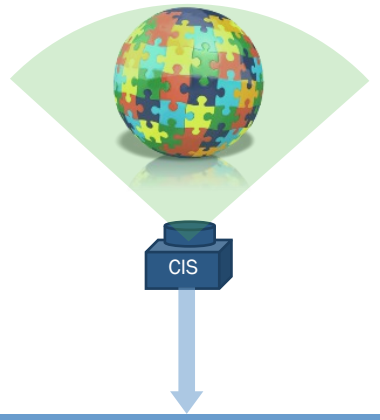
ToF
(Time of Flight)

Single sensor to measuring the IR pulsing light transit time difference



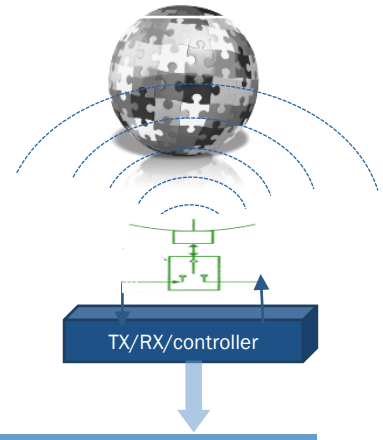
Super Depth

Single sensor Pixel level phase difference to create depth mapping



Radar
Radio Detection and Ranging

Utilize RF waves to compute velocity, and/or range to an object

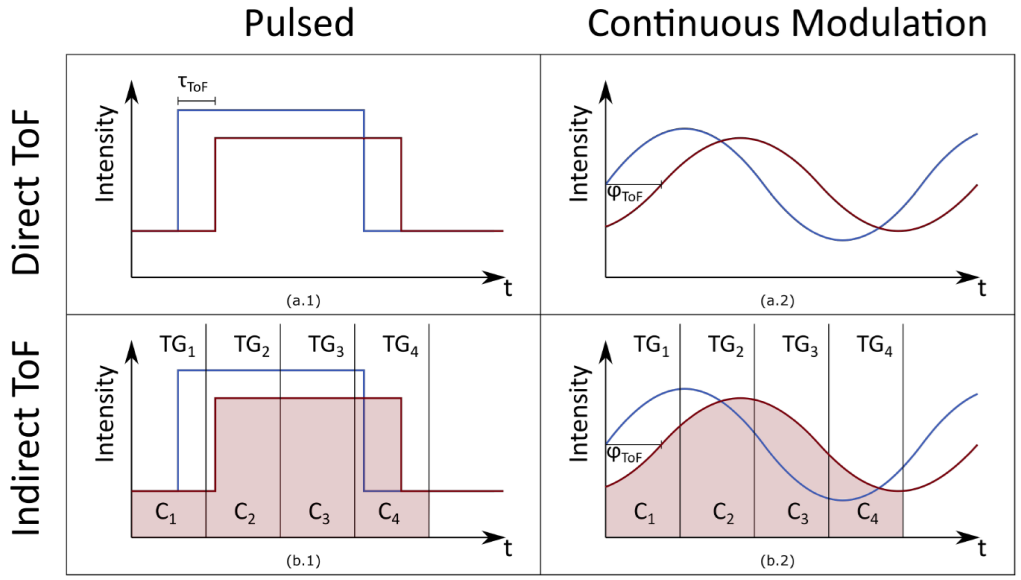


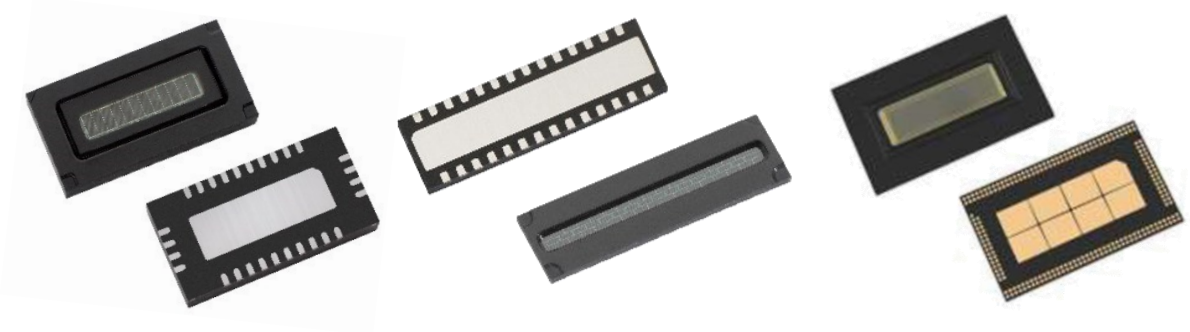
Imaging Analytics Algorithms

Application Software

Introduction – LiDAR with SPAD-based Sensors

- Principle: direct Time-of-Flight (dToF)
  - Time interval between controlled light emission and echo(es) detection
  - Phase domain → continuous dToF
  - Time domain → pulse dToF
    - Power efficient
  - Key benefits
    - Multiple echoes
    - Shot noise limited
    - High timing precision
- Single Photon Avalanche Diode (SPAD)
  - Single photon sensitivity
  - Fast and precise timing response
  - SPAD arrays and silicon photomultipliers array (SiPM)
  - Statistical behaviour (TCSPC)

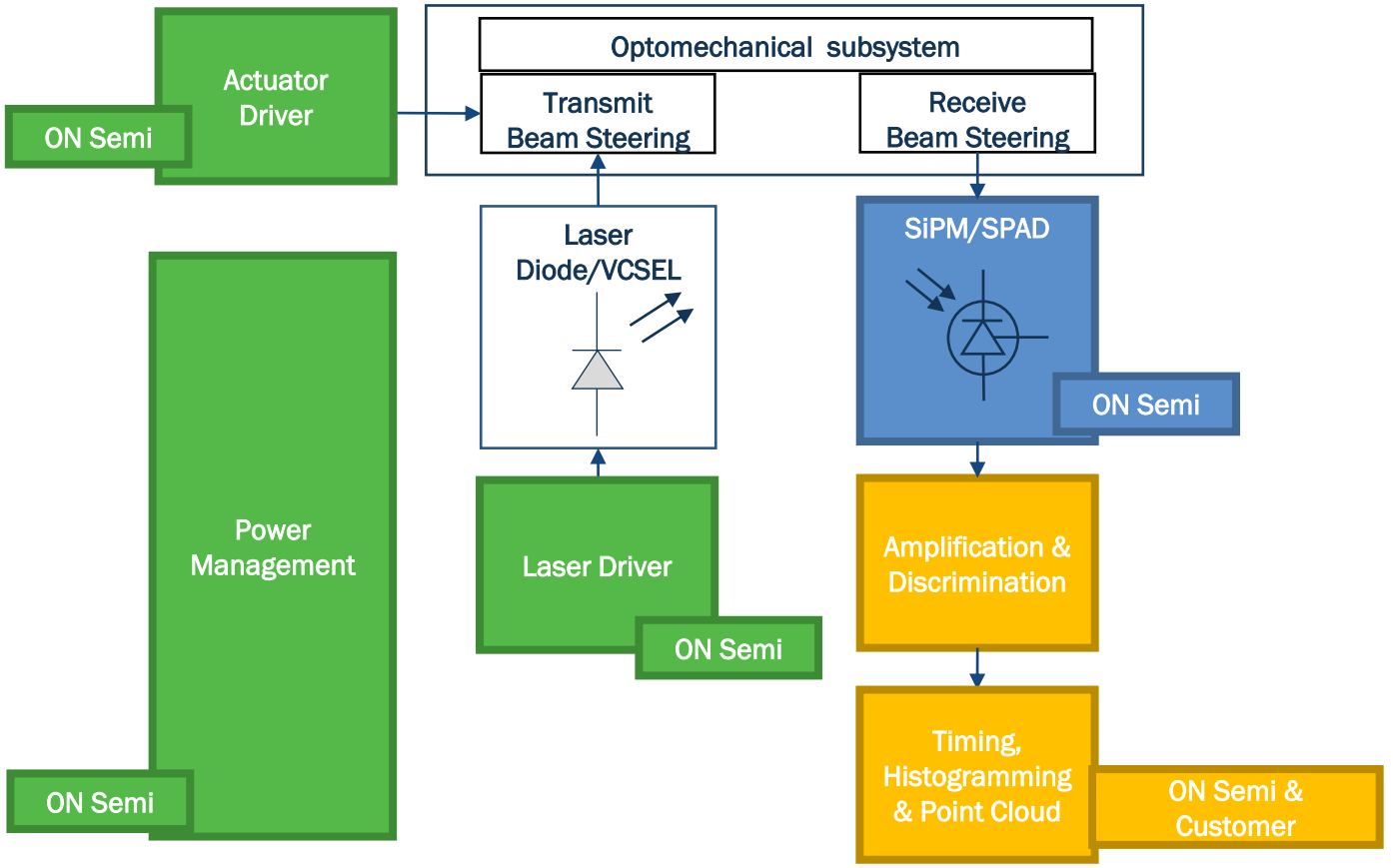




LiDAR Function Blocks

Six Major Hardware Functions block on a LiDAR System:

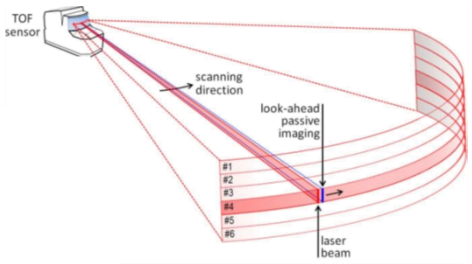
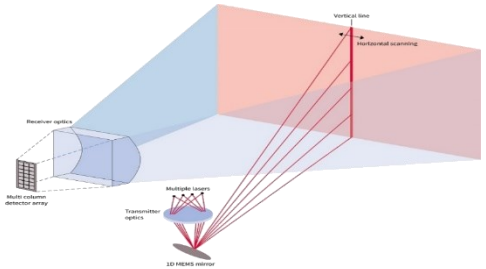
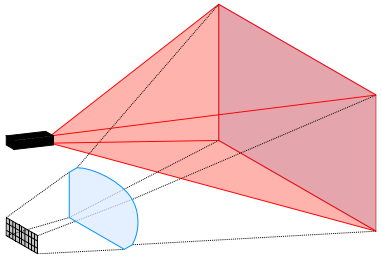
Transmit	• Illumination in NIR spectrum
Beam Steering	• Scanning/Scene Illumination
Optics	• TX and RX focus
Receive	• Return photon detection
Readout	• Signal processing and point cloud
Power and System	• Power management



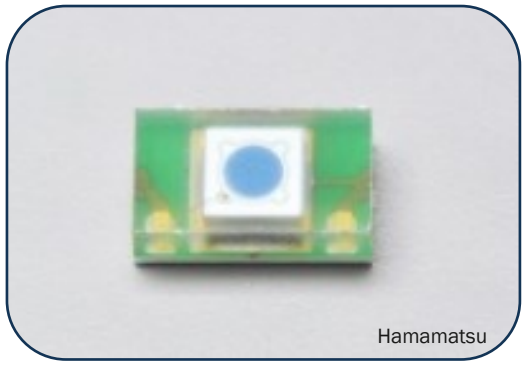
Typical LiDAR System Block Diagram

Key strategic focus for ON Semiconductor is to offer system, sensor, readout and laser driver solutions for all NIR LiDAR architectures

LiDAR Scene Illumination & Detection Methodologies

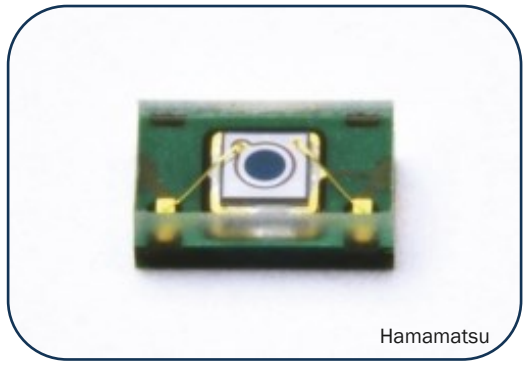
		Scanning Method	Challenges/Benefits
Rotating (2D or 3D)		• Mechanical • Galvo • Raster Scan	• System Alignment • Auto Qualification • Popular today
Beam-Steering		• MEMS | OPA • Scan on transmit/receive • Stare on receive only	• AoV tied to sensor • “Solid state” / solid state • Efficient for long-range
Flash		• No scanning • Staring emitter + detector • VCSEL array + SPAD array	• Angular resolution • Solid state • Shorter range

Types of Photodetectors for LiDAR



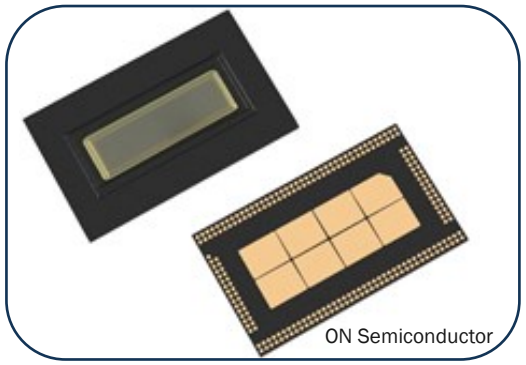
PIN Diodes

- ✔ Low Voltage
- ✔ Good Uniformity
- ✘ No Gain
- ⇓ Market Adoption



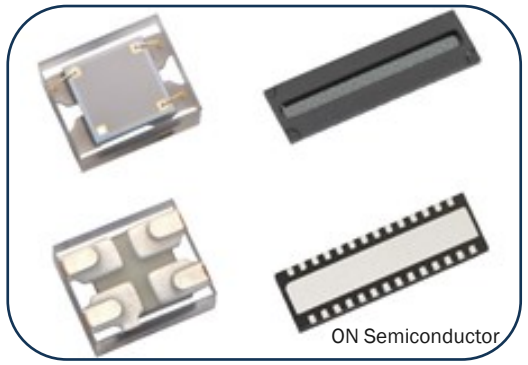
Avalanche Photodiodes & APD Arrays

- ✘ High Voltage
- ✘ Poor Uniformity
- ✔ Moderate Gain (10^2)
- ↘ Market Adoption



Single Photon Avalanche Diodes & SPAD Arrays

- ✔ Low Voltage
- ✔ Excellent Uniformity
- n/a (Geiger Mode)
- ⇗ Market Adoption



Silicon Photomultipliers & SiPM Arrays

- ✔ Low Voltage
- ✔ Excellent Uniformity
- ✔ Very High Gain (10^6)
- ⇗ Market Adoption

Higher Performance Detector = Better Ranging Performance

What is New on Detector Horizon?

SYSTEM BENEFIT:

Longer Range OR Less Laser Power

SPAD Arrays for LiDAR

Improved angular resolution

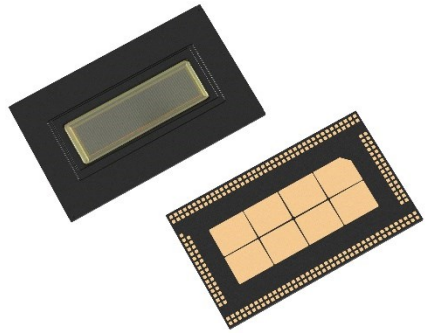
- Higher density pixels = higher resolution & more point cloud details

Better ambient light rejection

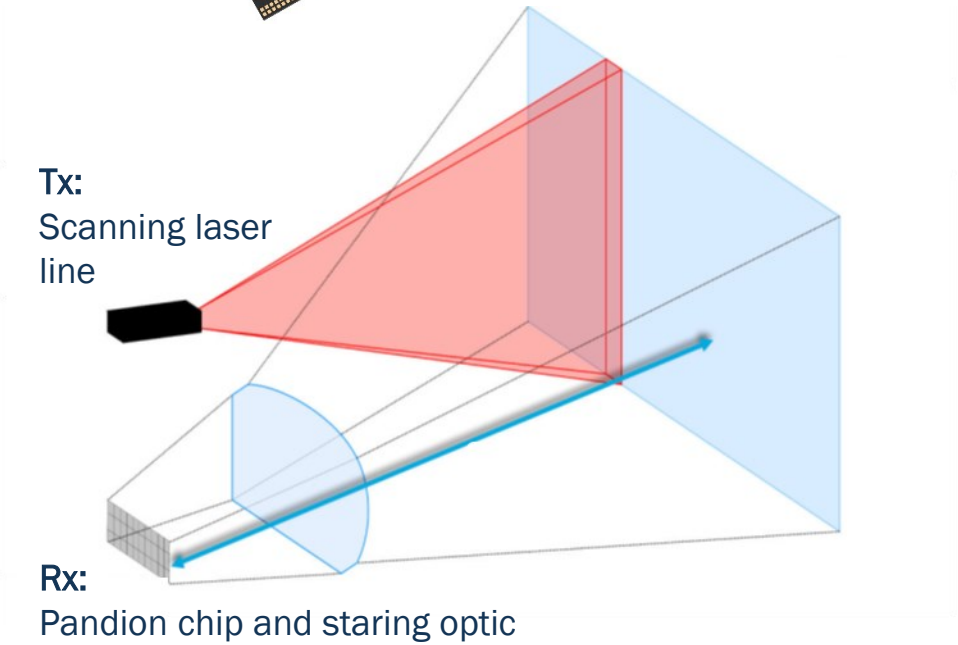
- <5ns recovery time = less dead time

Flexibility for low cost system design

- Flash for short range (<15m)
- Scanning for long range



Pandion SPAD Array



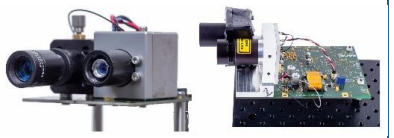
Example SPAD Array Architecture

Wide range of markets from automotive to consumer

LiDAR Reference Design & Demonstrator Plans

Gen1 & Gen2

Single Point



Gen3

Galvo scanning

100 meters

Mechanical LiDAR Reference Design

1x16 Mechanical scanning system

Discrete readout

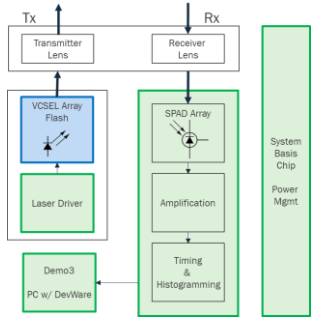
Discrete laser driver

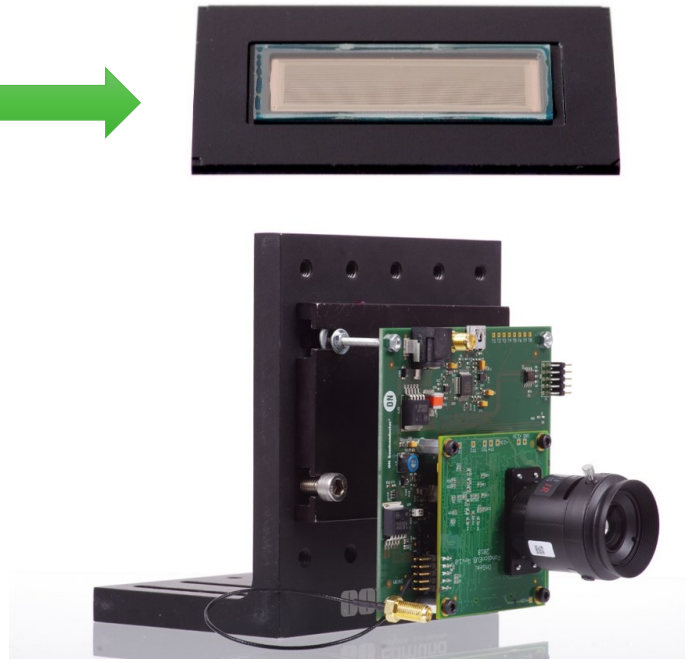
Power Management

Pandion SR Demo/EVK

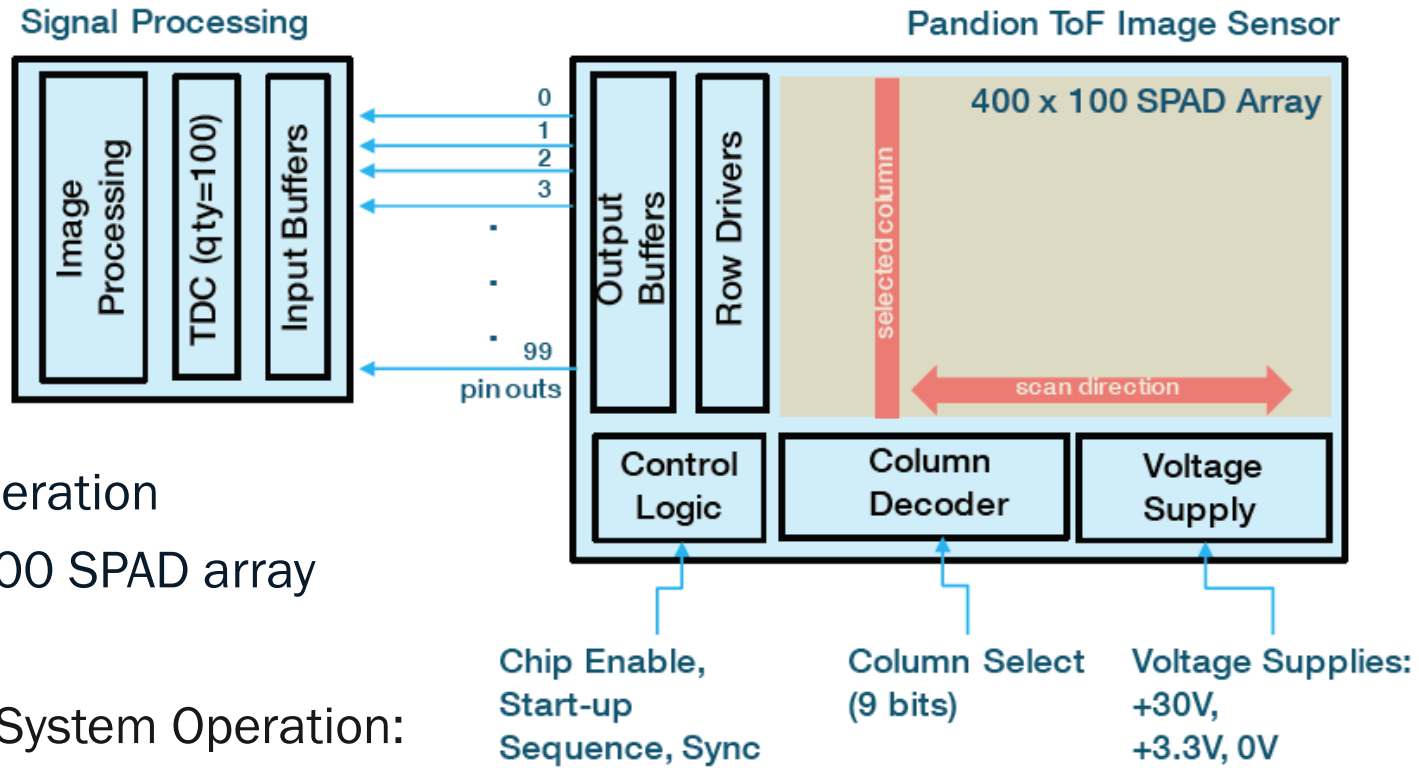
Pandion chip

Short distance demo using flash laser





Pandion Application Block Diagram



- 1st generation
- 400x100 SPAD array

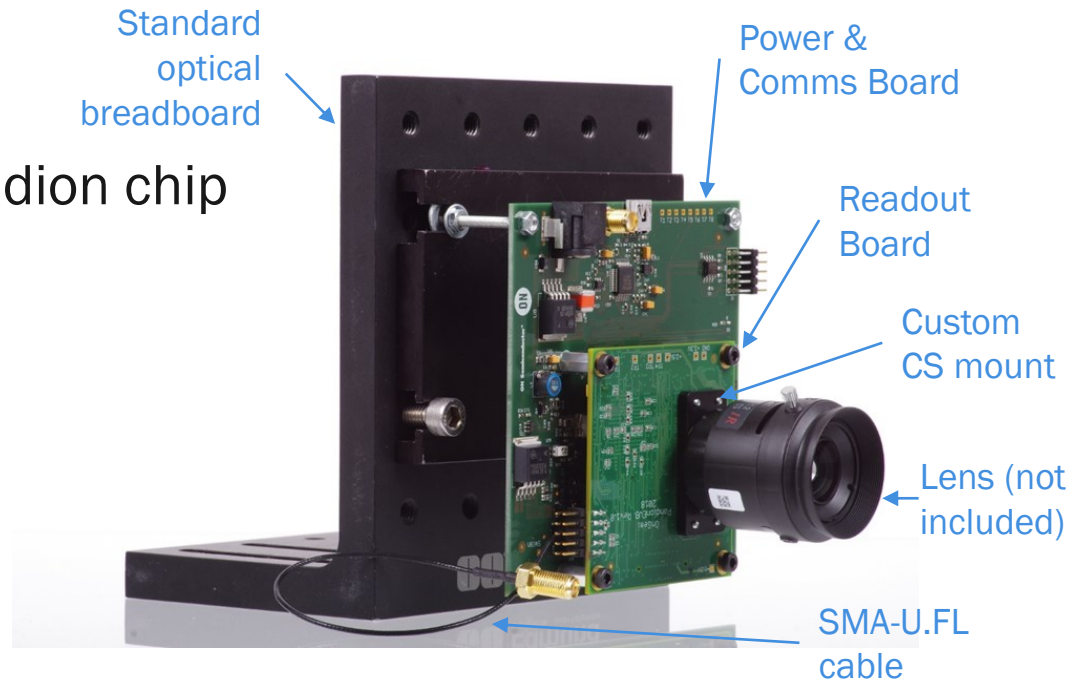
ARRAY SPECIFICATIONS

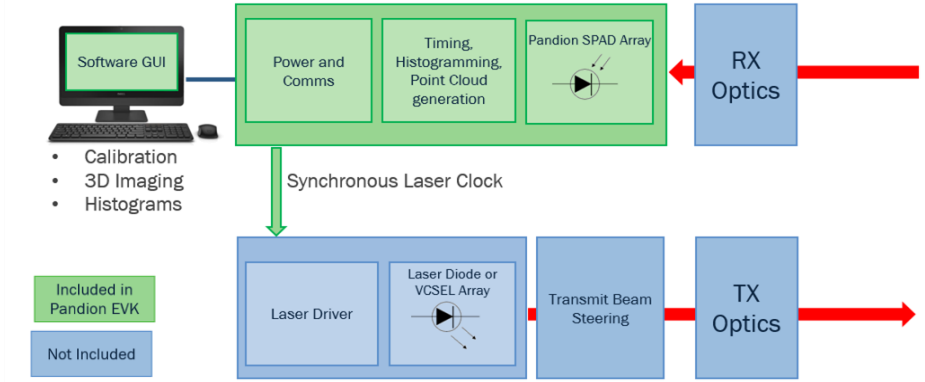
Parameter[1]	Value
Number of pixels	40,000
Array configuration	400 x 100
Array size	15.44 mm x 3.86 mm
SPAD size	31.9 µm x 12.1 µm
Pixel size	38.6 µm x 38.6 µm
Fill Factor	26 %
Photon detection probability @ 905 nm	~2 %
Temperature coefficient of Vbr	21.5 mV/°C

- Basic System Operation:
  - Select single column
  - Fire laser
  - Timestamp 100 signals with off-chip TDC
  - Scan laser and repeat for next column
  - Only one column is enabled for exposure/read at a time

Pandion EVK Details

- Plug-and-play system for quick evaluation of the Pandion chip
- The Pandion EVK contains:
  - Readout Board
    - Pandion chip
    - FPGA based TDC
  - Power & Communications Board
  - Universal Power supply & cable
  - GUI
  - Lens mount for CS lens
  - User Manual
- Additional Requirements for ToF Imaging
  - Detector Optics
  - Illumination source
    - Laser clock signal available on comms board for sync
  - U.FL compatible cable to connect laser clock
    - E.g. SMA to U.FL cable (digikey link)
  - Alignment of Tx and Rx





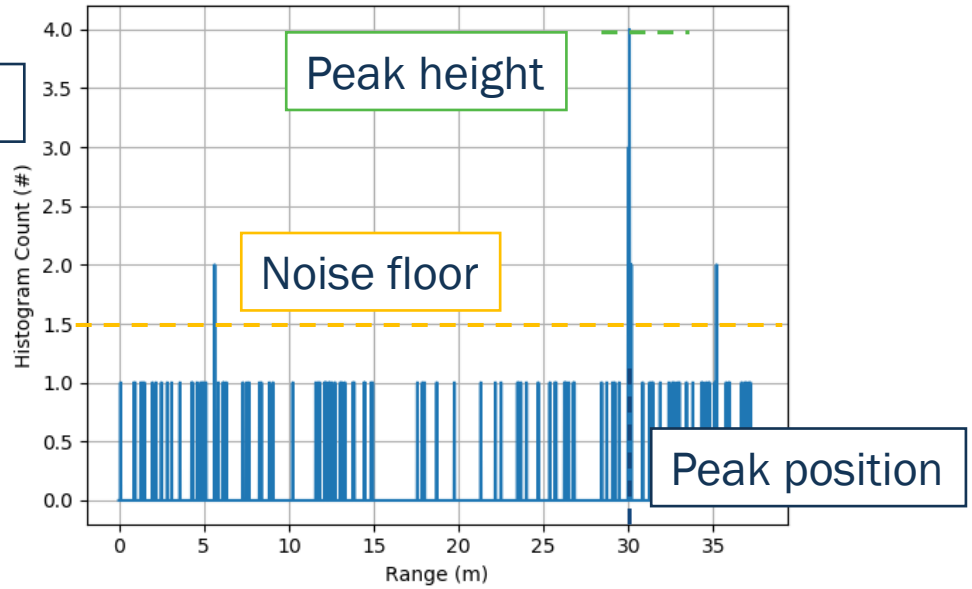
Pandion EVK Readout– Histogramming – Depth and Intensity

- N laser pulses per acquisition (measurement)
- Sensor + TDC response stored in histograms (top)
- Information in the histogram
  - Noise floor
    - ambient light
    - object reflectivity
  - Peak
    - position → distance
- Noise: time-uncorrelated peak: time-correlated
  - A correlated histogram can be built (bottom)
    - better SNR
    - higher confidence of peak extraction

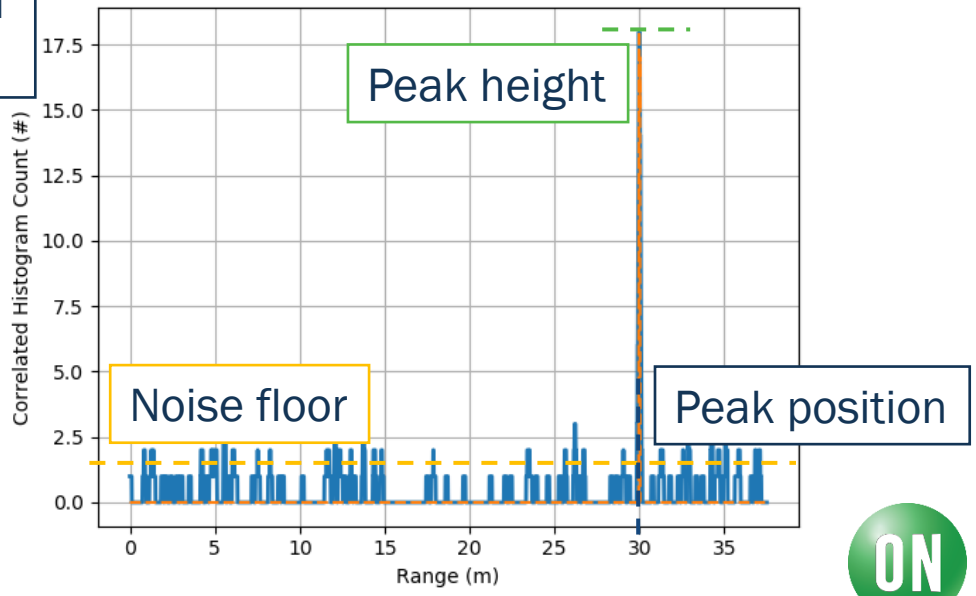
Intensity

Depth

Histogram



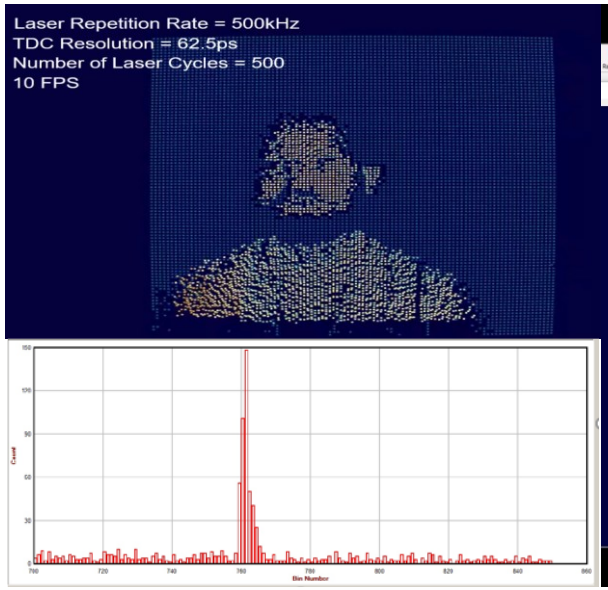
Correlated Histogram



Pandion EVK – 3D and Intensity

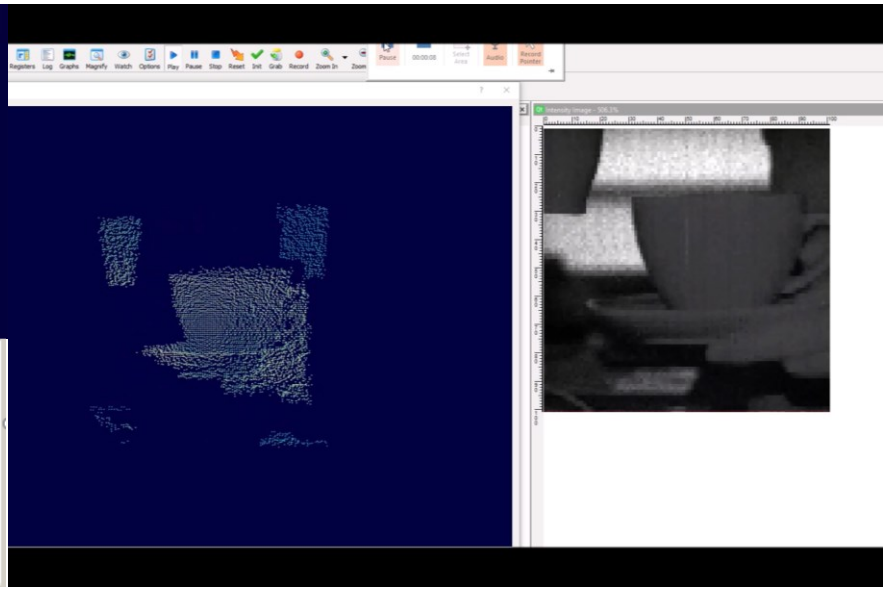
- GUI can show
  - Depth point cloud
  - Individual pixel histograms
  - Intensity picture
- How?
  - FPGA generates and store histograms
  - Peak position → depth map
  - Noise floor counts → intensity
  - Software does 3D rendering

Point cloud



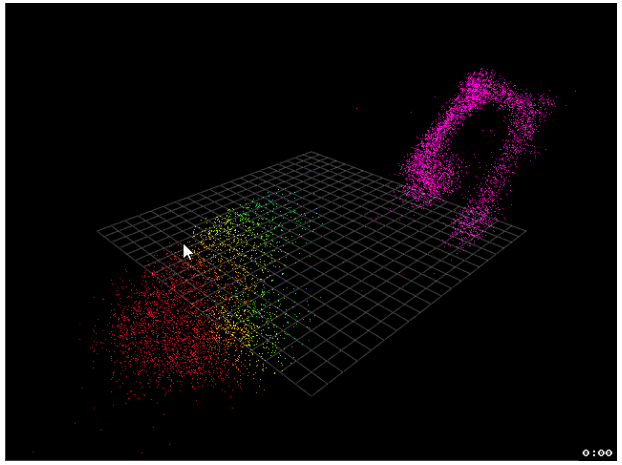
Histogram

Depth map + Intensity

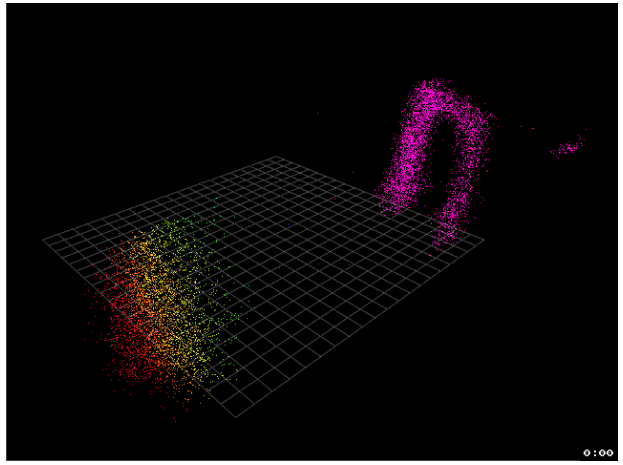


Data Rendering: Applying Filters to Pandion Point Cloud

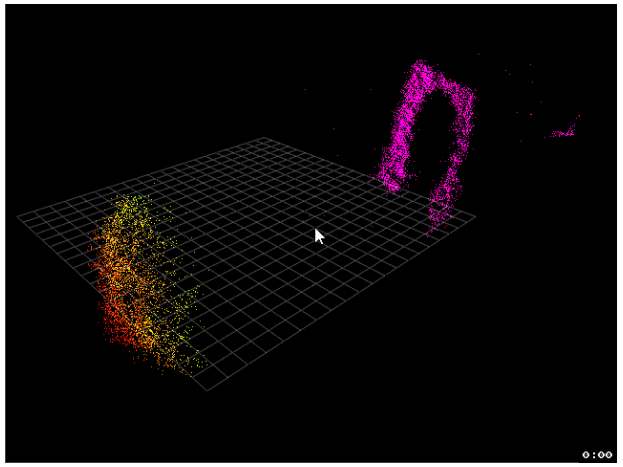
(1) Raw Data



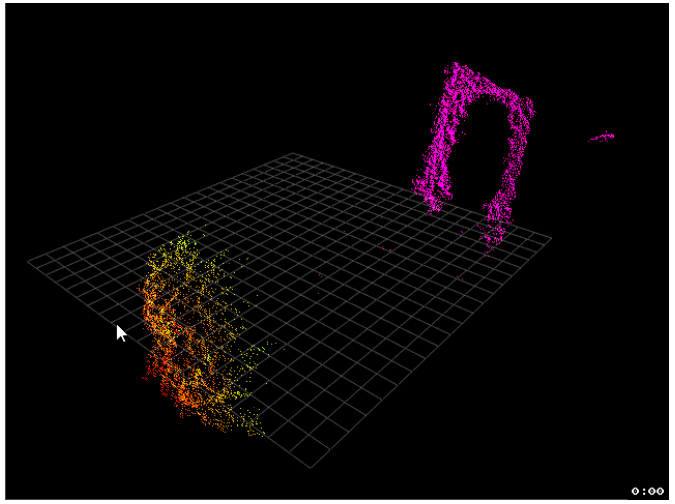
(2) Subtraction of a Flat Wall



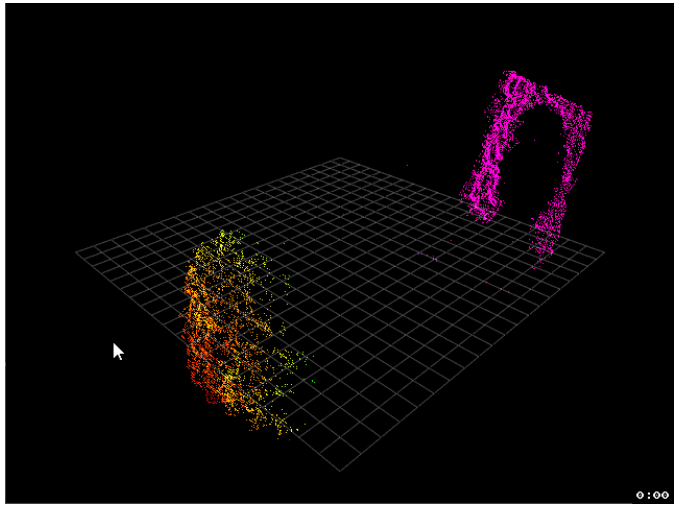
(3) + Spatial Bilateral Filter (Kernel size = 5)



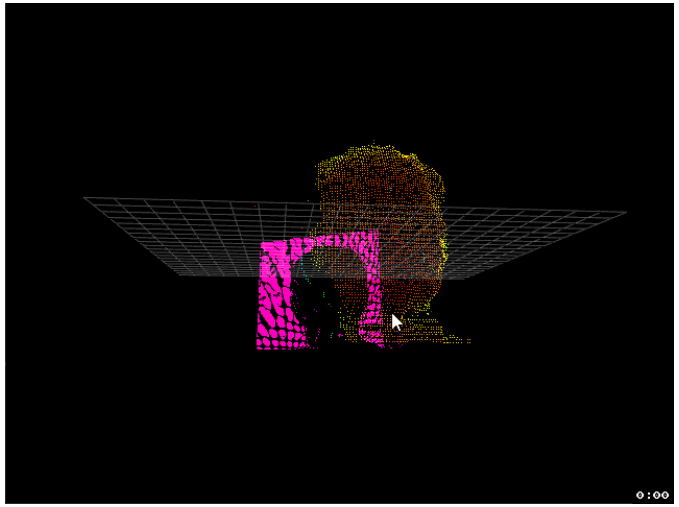
(4) + Spatial Median Filter (Kernel size = 3)



(5) Remove Out of Bounds Pixels



(6) +Temporal 5 frame averaging



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Public Information

Appendix