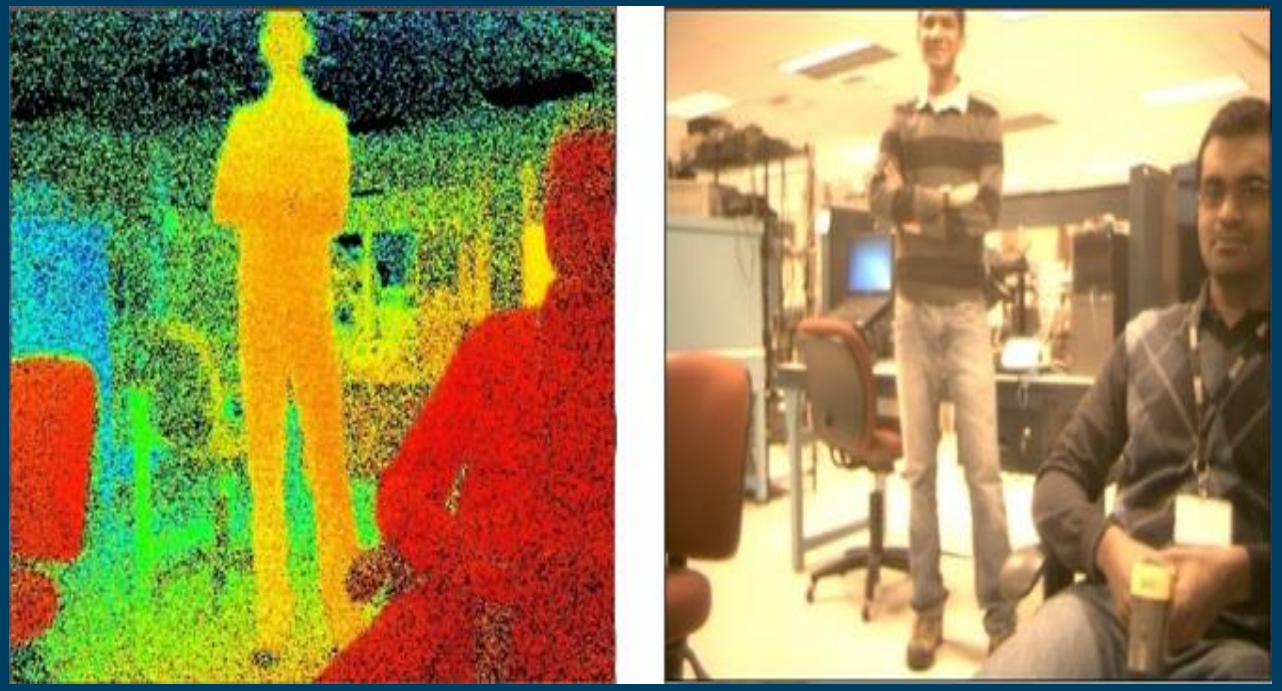
ANALOG DEVICES

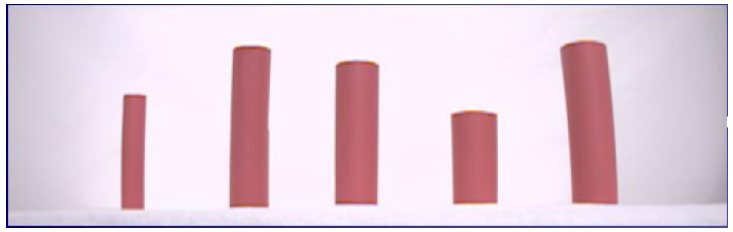
AHEAD OF WHAT'S POSSIBLE™

ADI 3D DEPTH SENSING

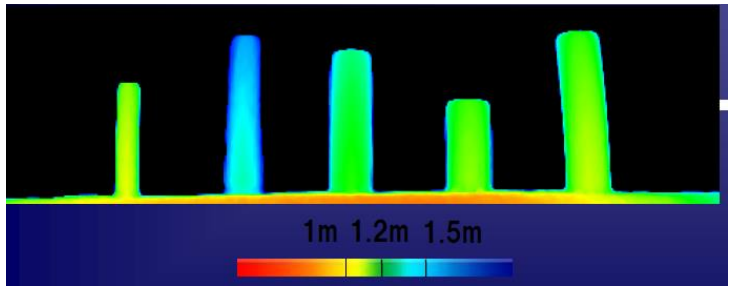


3D Depth Mapping

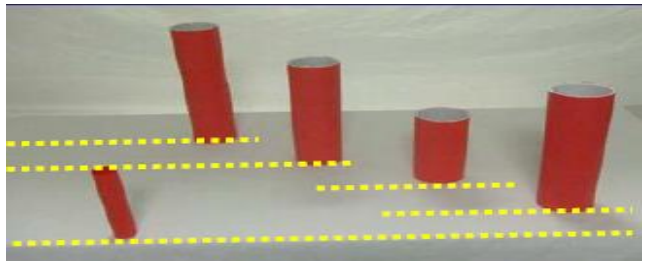
- Enables the user to get a human-scale understanding of its environment in the 3rd dimension - i.e., it would make the camera aware of its surroundings in terms of *how far away* the objects are as well as the *actual mass* or *scale* of each of those objects.
- Example: which pole is closest to the camera?



RGB Camera



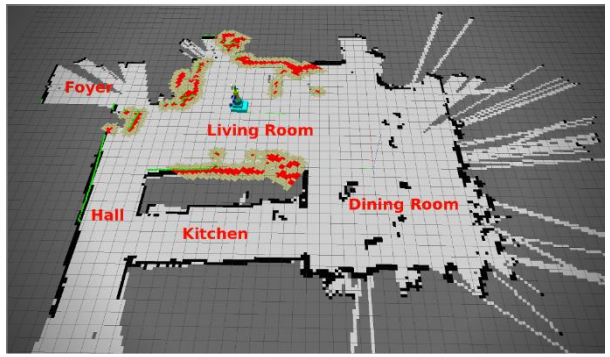
Depth Detection Camera



Distances between the dotted yellow lines can be measured

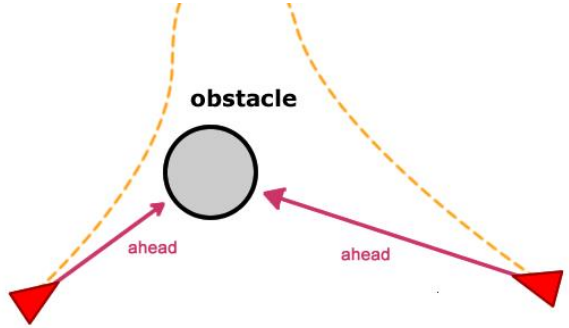
Depth Maps

3D Depth Mapping Use Cases

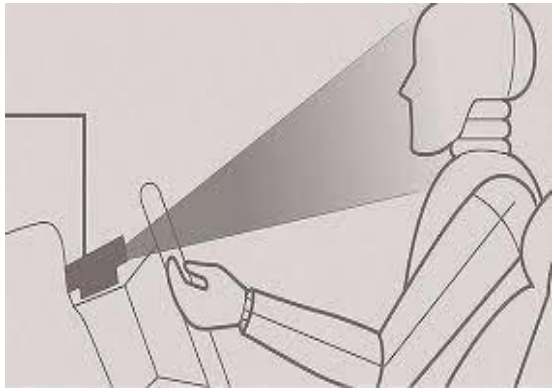


SLAM (Simultaneous Location and Mapping)

Gesture Control



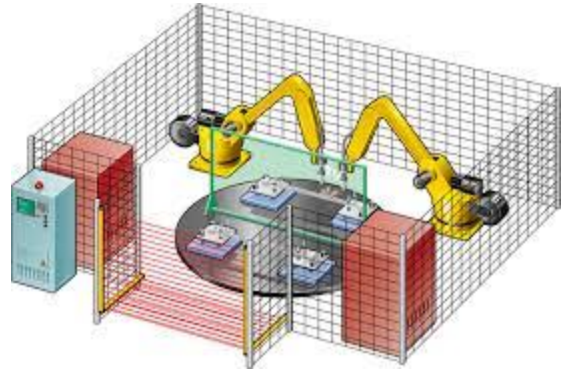
Object Avoidance



DMS / Passenger monitoring

People Counting

3D scanning



Safety / Proximity Sensing

3D Depth Mapping Applications

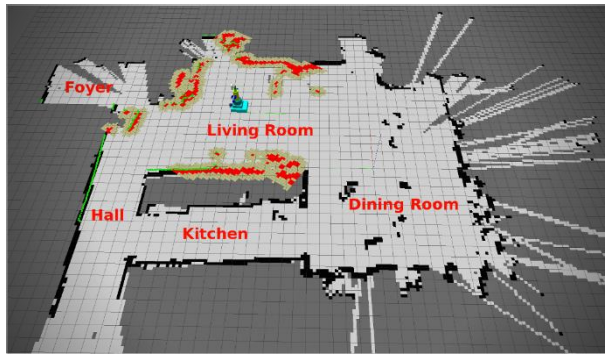
AR/VR

Drones

Industrial Applications

Automotive Applications

Surveillance/People Counting Applications

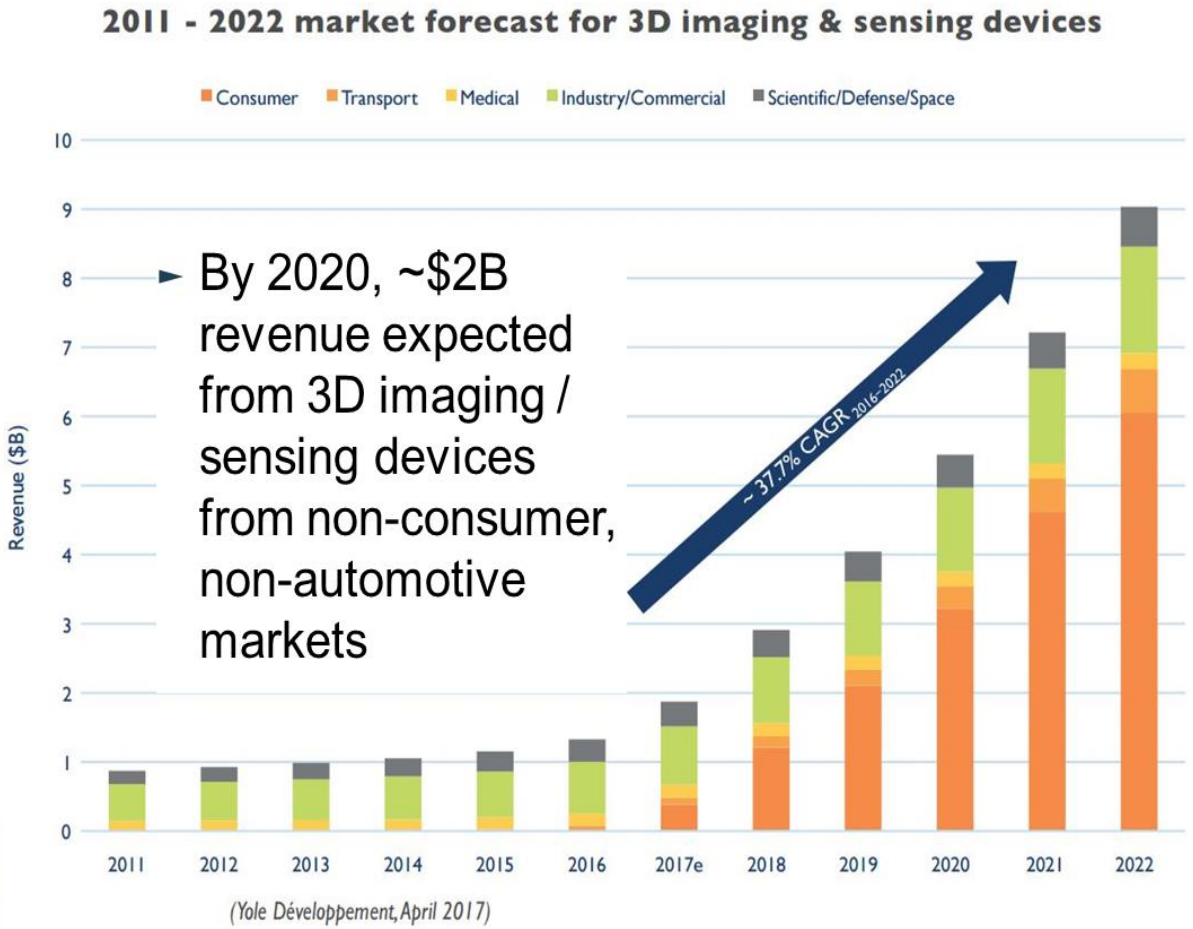


SLAM (Simultaneous Location and Mapping)

- Service Applications
- Home Robotics
- Warehouse Robots
- Autonomous Factories

ADI Time of Flight Depth Sensing Broad Market

- Strong pull towards broad market application areas for TOF, including:
  - Security / Surveillance / People counting
  - Robotics (Factory and AGV)
  - Logistics and Transport (supply chain management, machine vision, building management, etc.)



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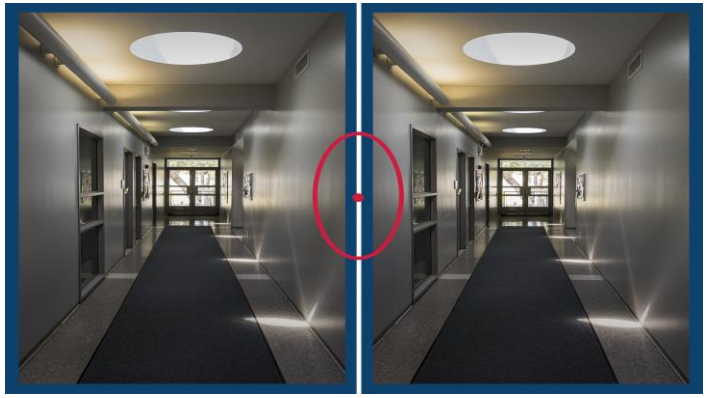
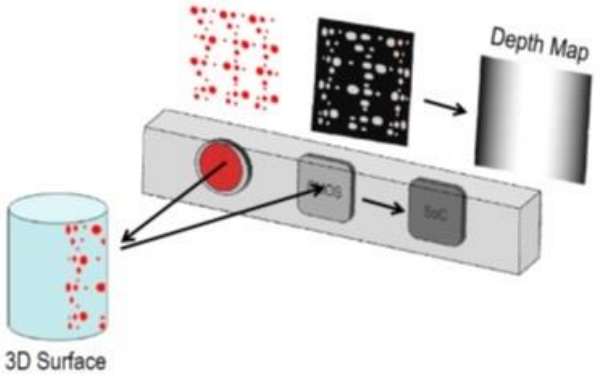
AHEAD OF WHAT'S POSSIBLE™

Depth Sensing Technologies

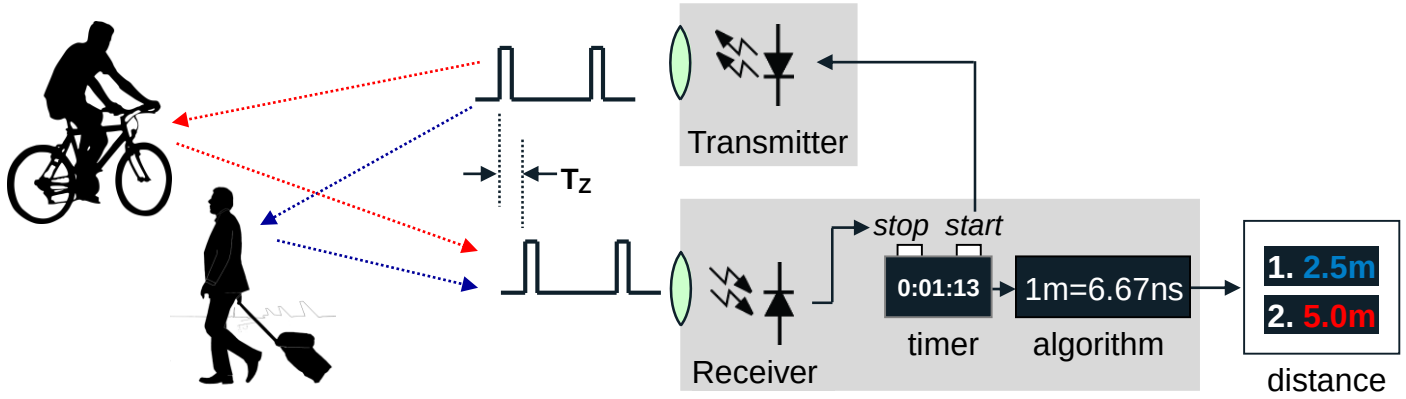
- **Stereoscopic**
  - Used in smartphones and other applications
  - Advantages: passive lighting system (only requires two cameras + application processor (AP))
  - Disadvantages: doesn't work in dim or dark environments, object needs to have contrast to be detected (won't work on a white wall); longer distances require cameras to be farther apart



- **Structured Light**
  - Used in Microsoft Kinect (1st Generation) and iPhones
  - Advantages: very precise measurements at close distances (<1m)
  - Disadvantages: does not work well in bright environments, longer distances (>2m); larger form factor; calibration difficulties during MP

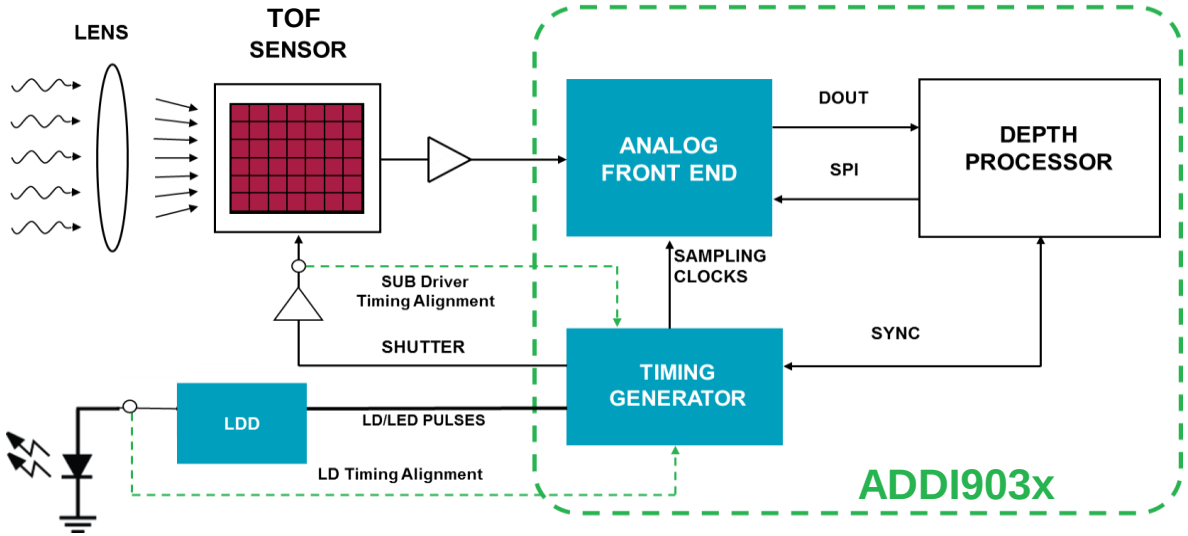


TOF Concept for 3D Depth Imaging



1. Transmit IR optical pulse
2. Synchronously receive the optical reflection
3. Measure the time delay between the Tx and Rx pulses:
   T_Z = Time-of-Flight
4. Use the speed of light to calculate the target distance

Time-of-Flight (TOF) CCD Depth Camera

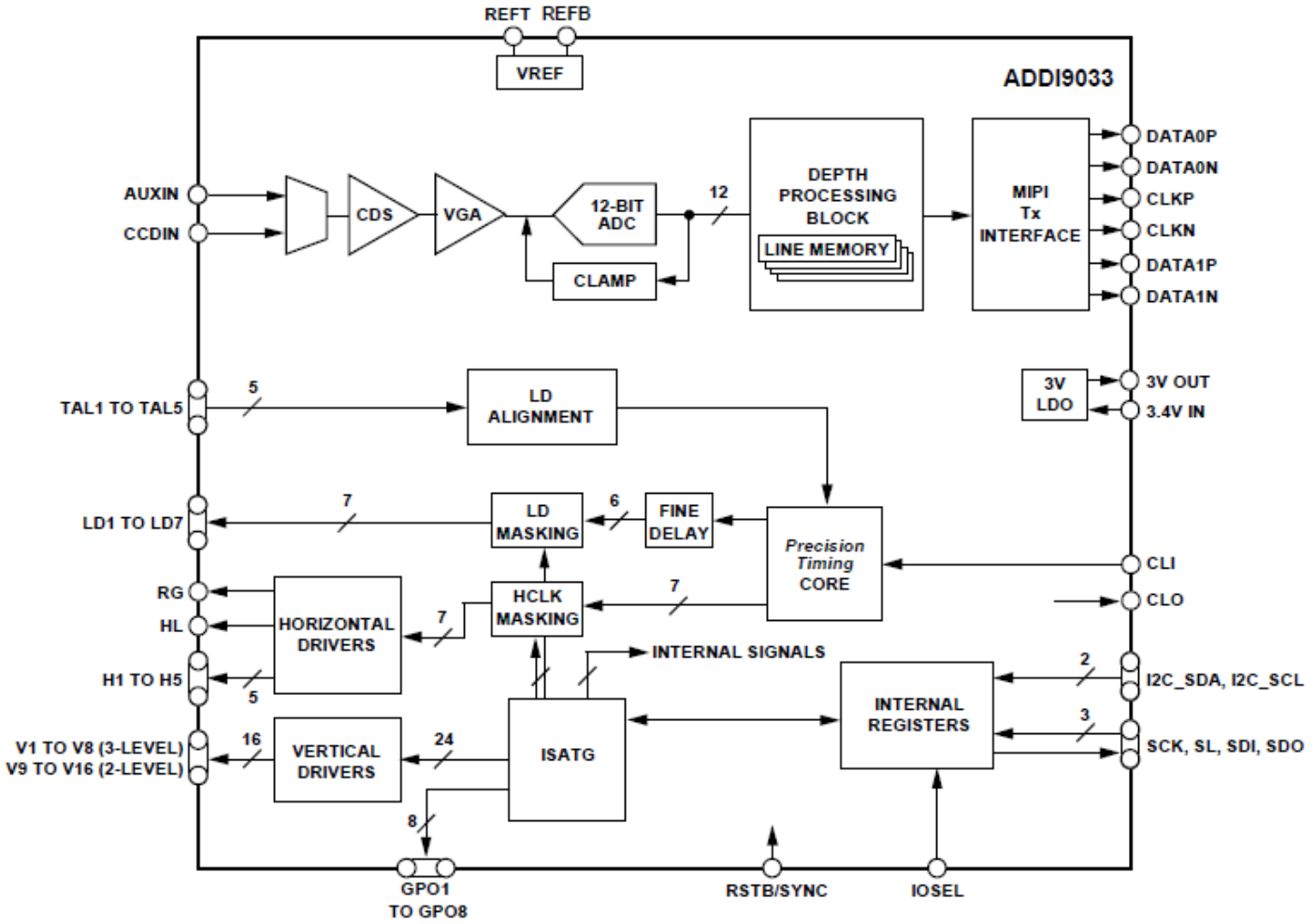


TOF CCD System Features

- Wide dynamic range: flexibility to detect close (<10cm) to far distances (>15m) depending on laser
- Image and depth information in QVGA / VGA resolution
- 940nm illumination makes imaging possible in strong ambient light (see next slide)
- More power efficient at longer distances (smaller duty-cycle with pulsed TOF)
- Global shutter sensor – less motion blur
- Multiple systems can be operated in the same environment without interfering with each other

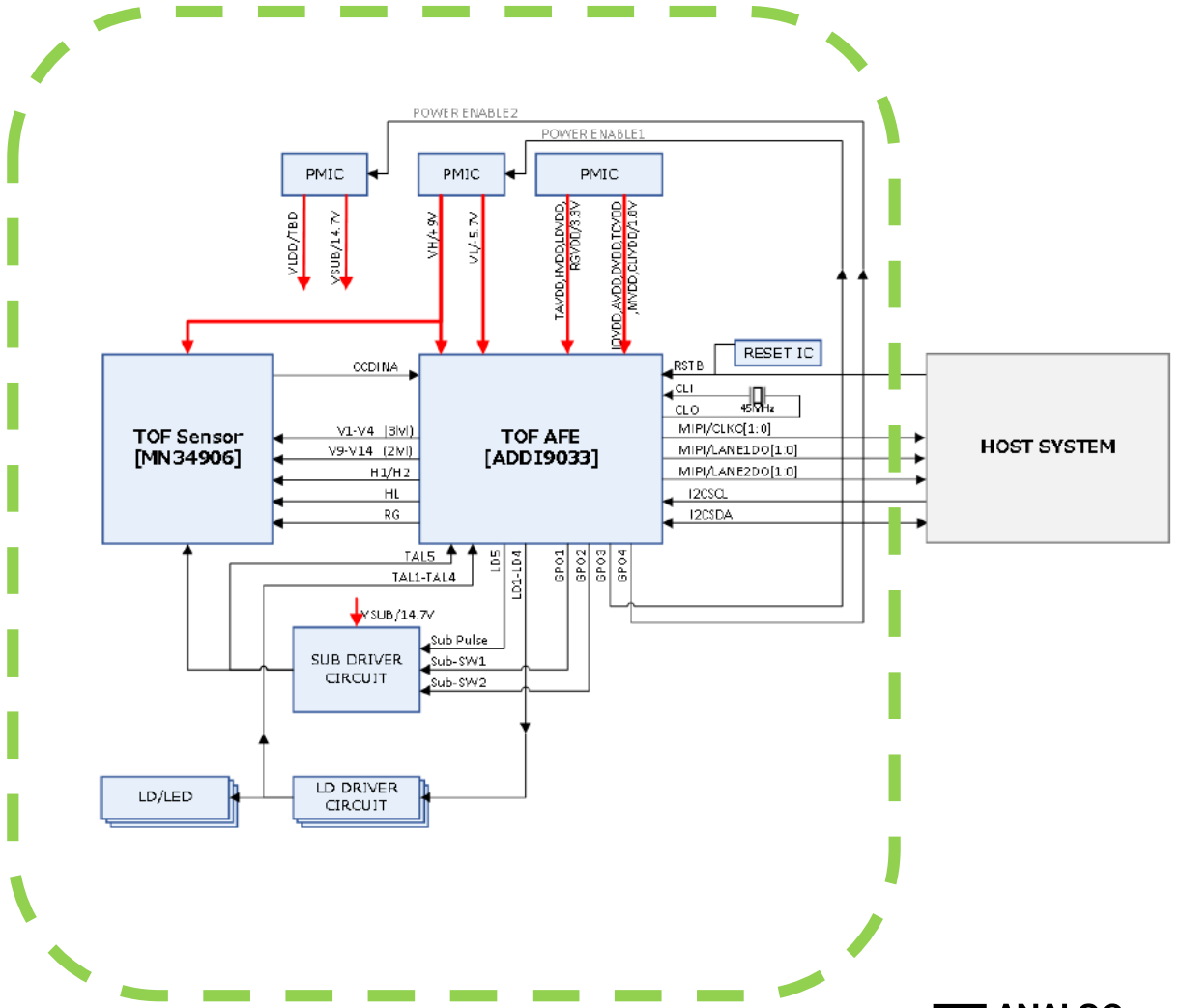
ADDI9033 / 5/ 6: TOF Signal Processor with Programmable Timing and V-driver

- 12-bit, 45MSPS AFE
- Internal Timing Generator
  - Integrated horizontal and vertical clock drivers
  - Integrated timing clock for laser diodes
  - *Precision timing*^{tm} core with 174ps resolution
- Internal Depth Processor
- Closed feedback loop provides dynamic timing alignment
- ADDI9033
  - 8mm x 8mm, 12-ball CSP_BGA package
  - AEC-Q100 Grade 2 / ASIL-QM
- ADDI9035
  - SPI I/F only
  - 6mm x 6mm WLCSP
- ADDI9036
  - I2C I/F only
  - 6mm x 6mm WLCSP

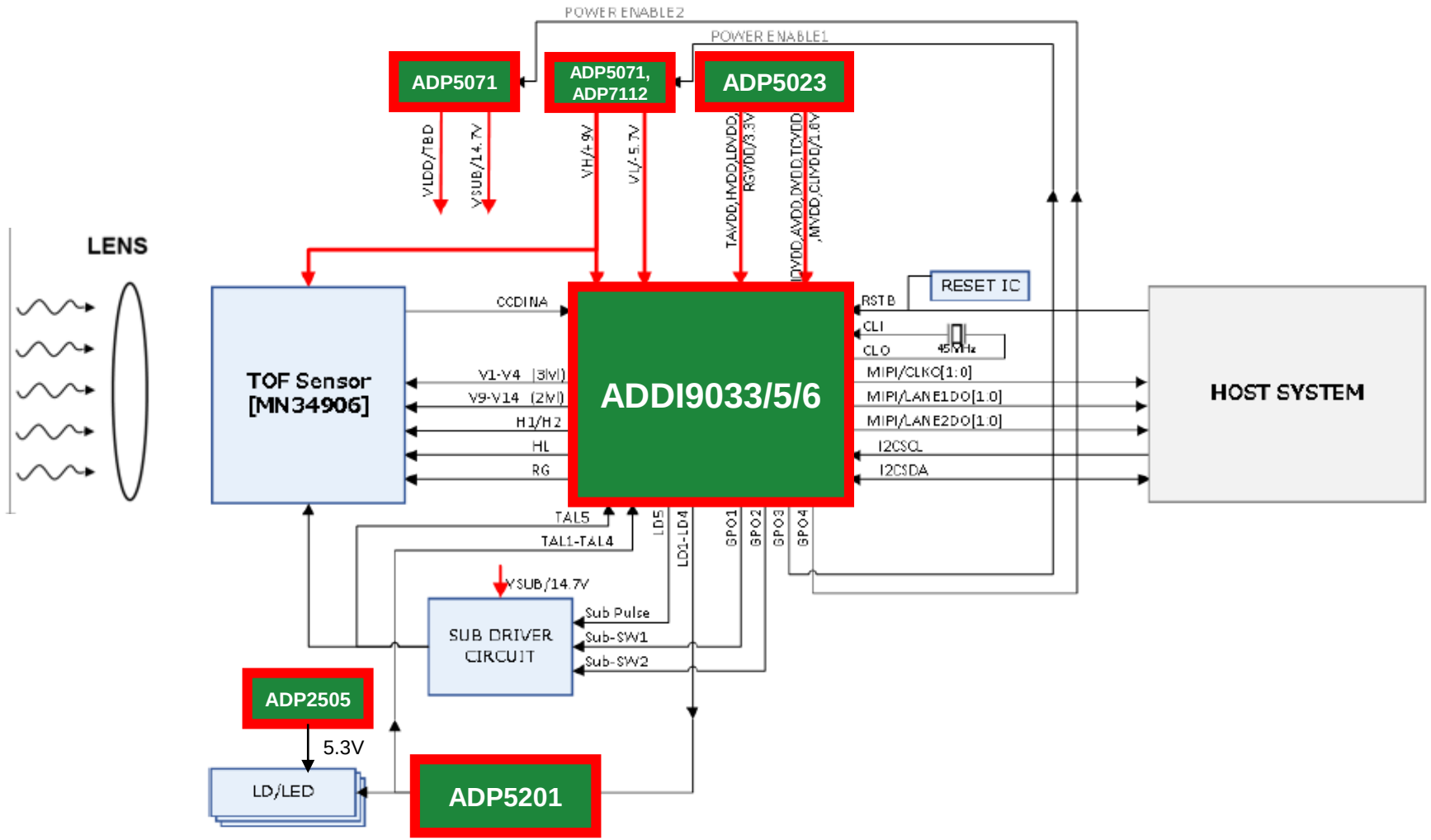


ADDI9033 Evaluation Board / TOF Module Availability

- ADDI9033 Evaluation Board
  - EB with ADDI9033, MN34906 (CCD), VCSEL (Princeton Optronics)
  - GUI Software
  - Windows / Linux SDK
- TOF Module in Development
  - Much smaller form factor
  - USB powered
  - Less flexibility than the evaluation board



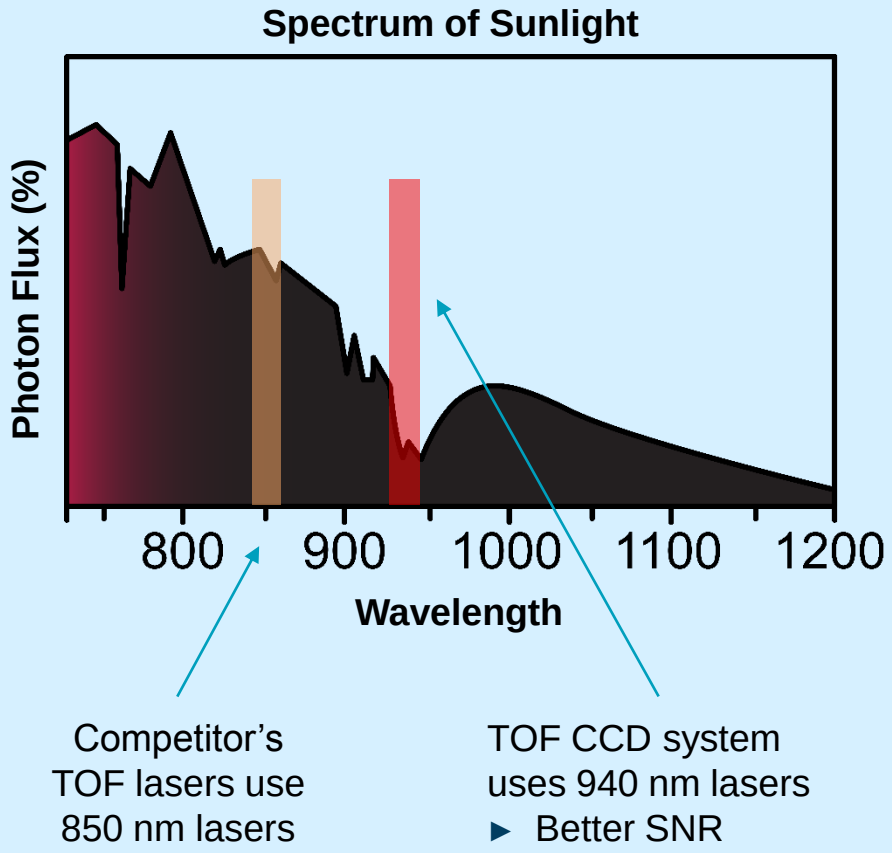
TOF System Block Diagram - Laser Diode Driver + VCSEL



ADI TOF system level spec

		ADDI9035	System Level advantage
1	Pixel Size	5.6 x 5.6 um	- Smaller chip size or higher resolution - Noise performance better than CMOS BSI
2	Resolution	VGA	Much better details especially in complex scenarios
3	Global Shutter	Yes	Better motion capturing
4	Pulsing scheme	4ns ~ 22ns, duty cycle = 2.5% to 10%	Better optical power efficiency and thermal management
5	Sensitivity @ 940nm	Special design for 940nm	- Better outdoor performance - Higher QE than CMOS
6	Output Data	Depth only, Depth + IR, low power IR, Confidence map	Higher software flexibility
7	Embedded Processor	Flexible to support all system functions	Support more features such as Auto Exposure control, Wide Dynamic Range, Low power timing… etc
8	Temperature Drift	Hardware supported function	Self compensation in temperature difference.
9	Multi-system Anti-Interference	Hardware supported function	Multi system can be used in same space
10	Anti-EMI	Hardware supported function	
11	Calibration scheme	Ready to use	

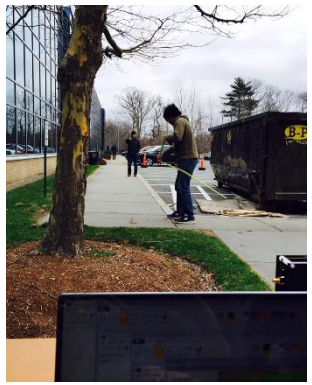
TOF CCD Camera Offers Superior Outdoor Performance



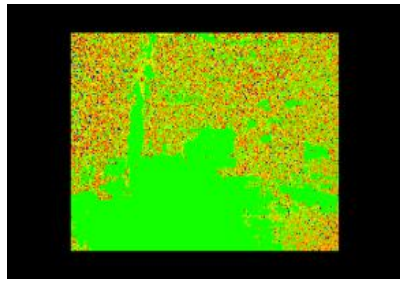
Competitor's TOF lasers use 850 nm lasers

TOF CCD system uses 940 nm lasers

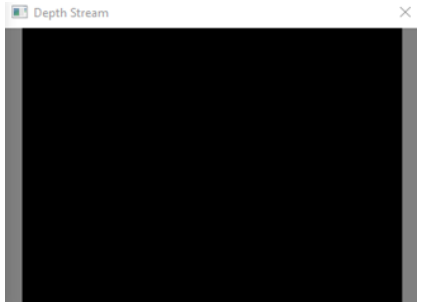
- Better SNR



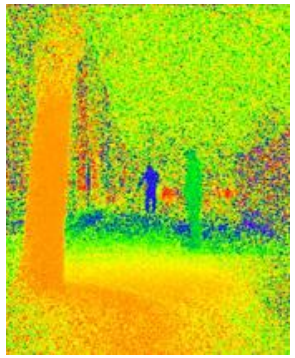
RGB



CMOS TOF



Structured Light

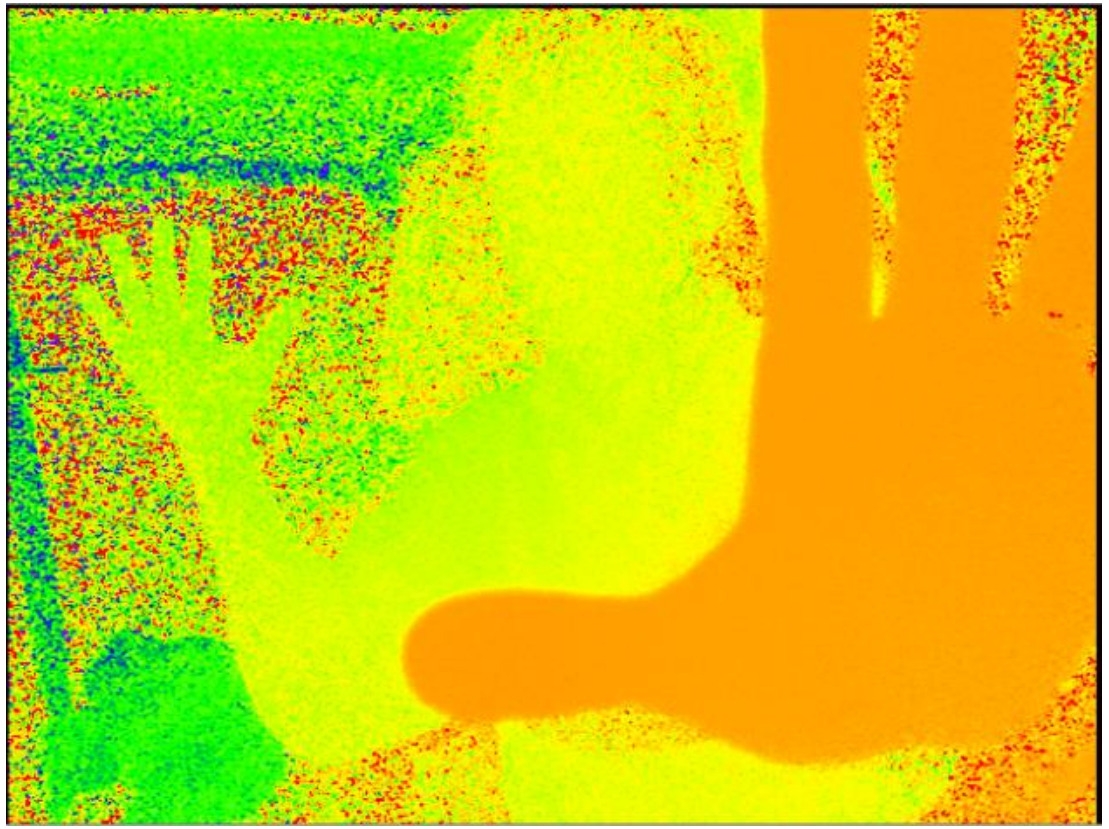


ADI TOF CCD

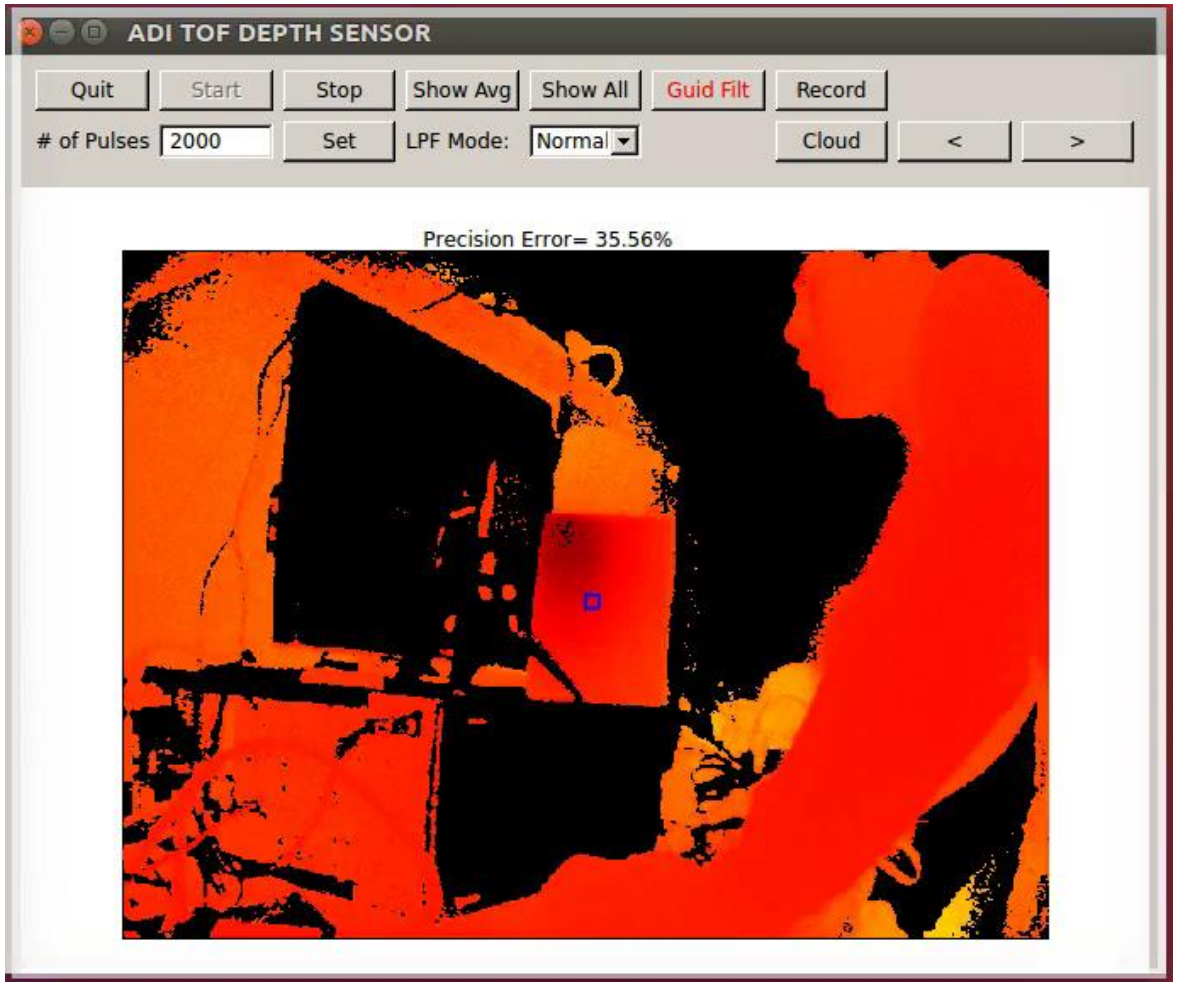
ADI TOF solution unique advantages

- **Higher sensitivity @ 940nm**
  - **Proved better outdoor performance**

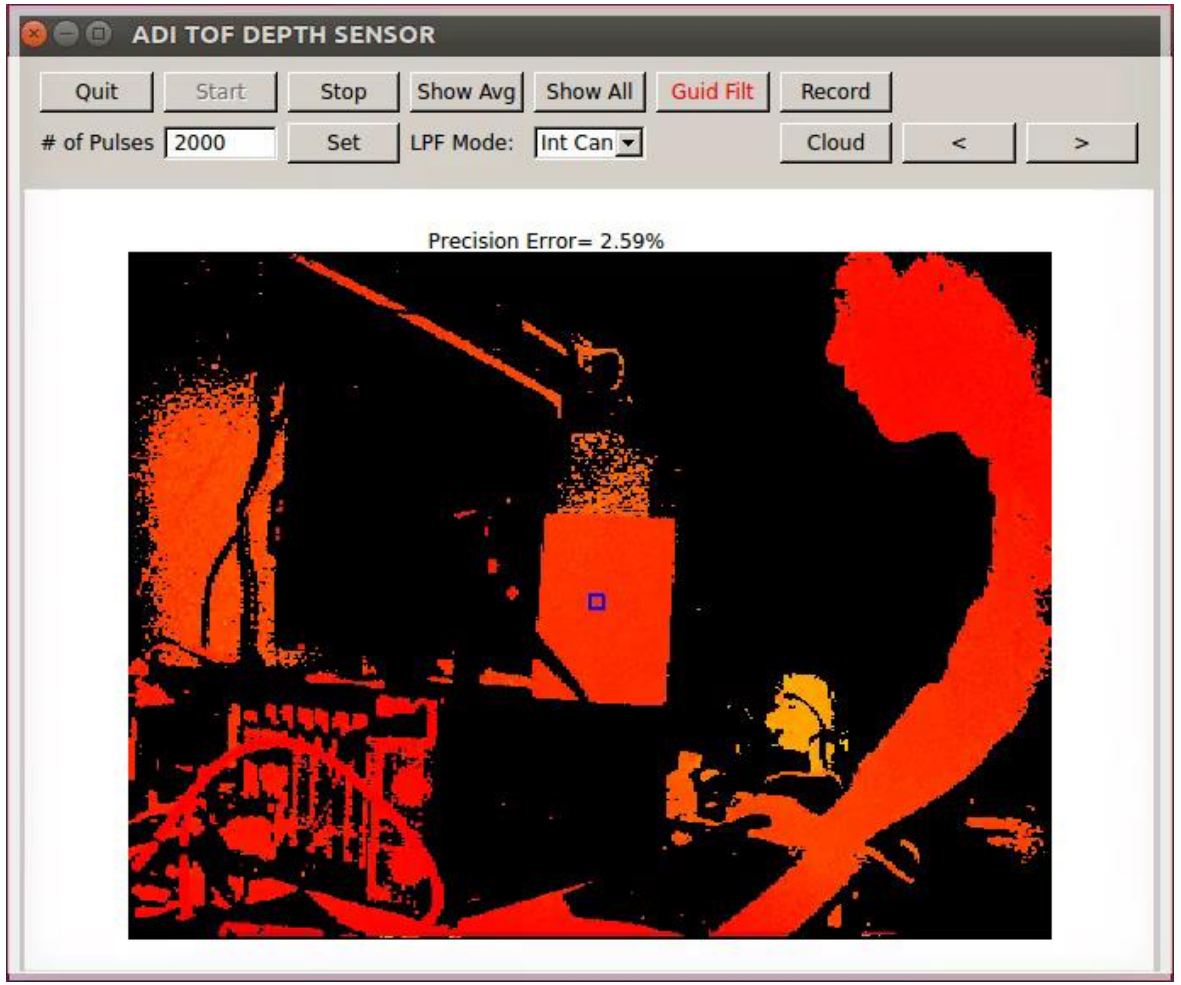
TOF CCD image inside car with 70K Lux of light (>100K lux outdoors) (ADI)



Interference Cancellation (With / Without)

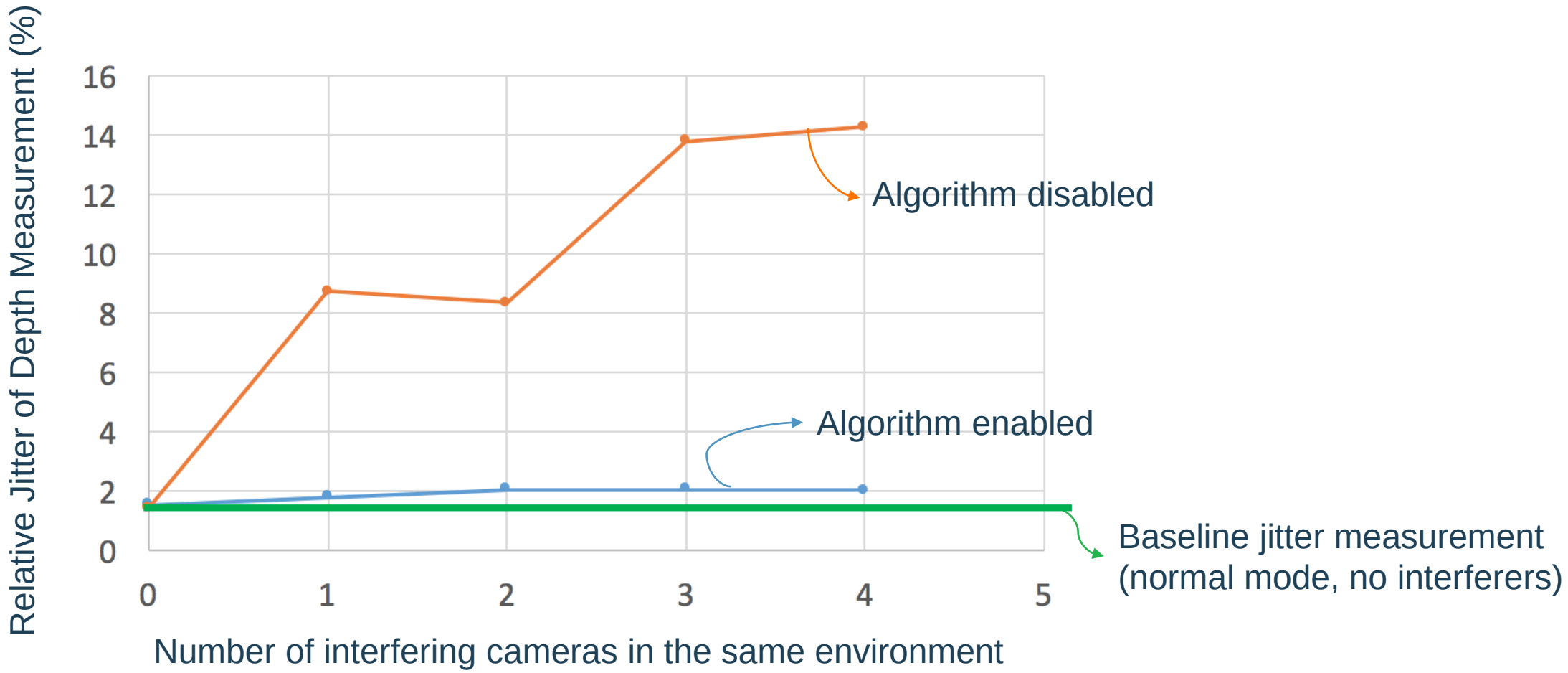


Without Interference Cancellation

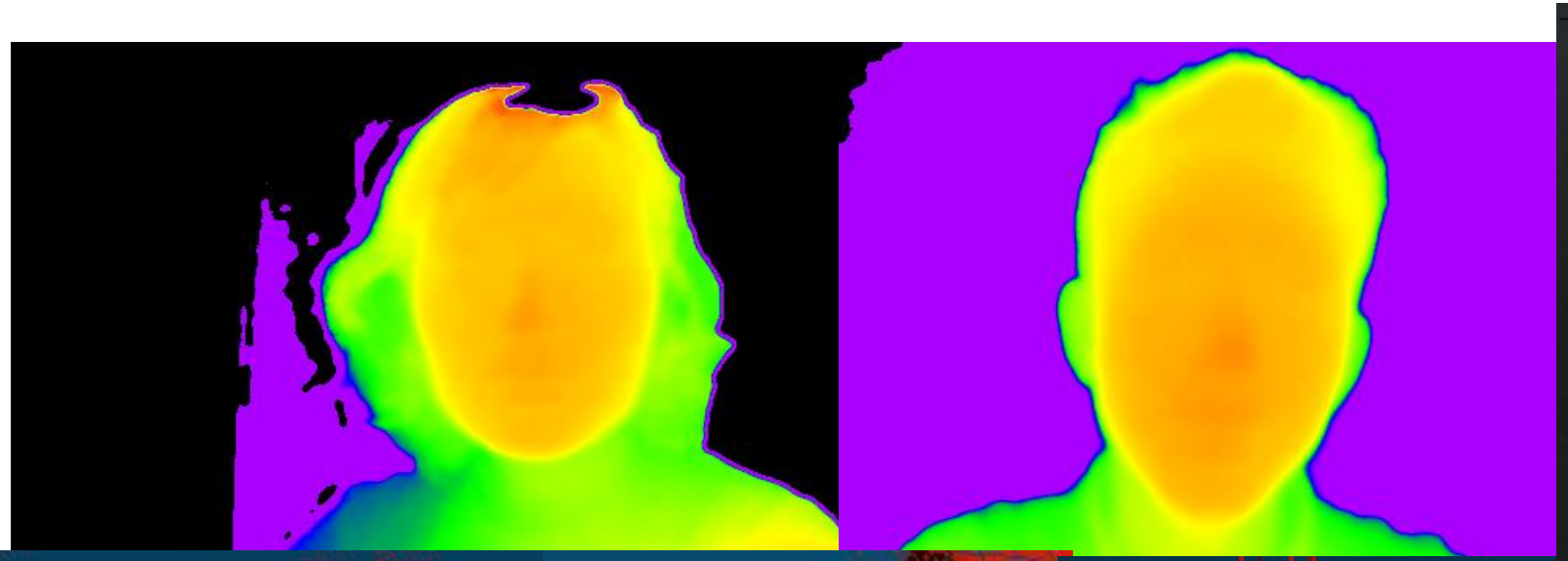


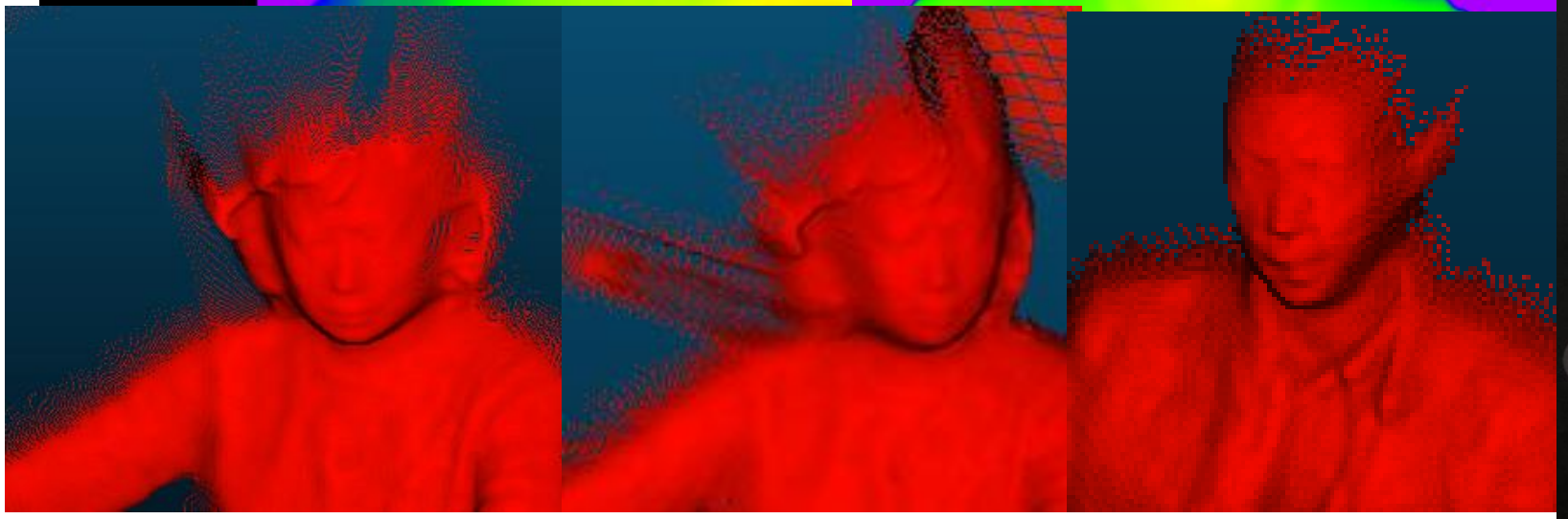
With Interference Cancellation

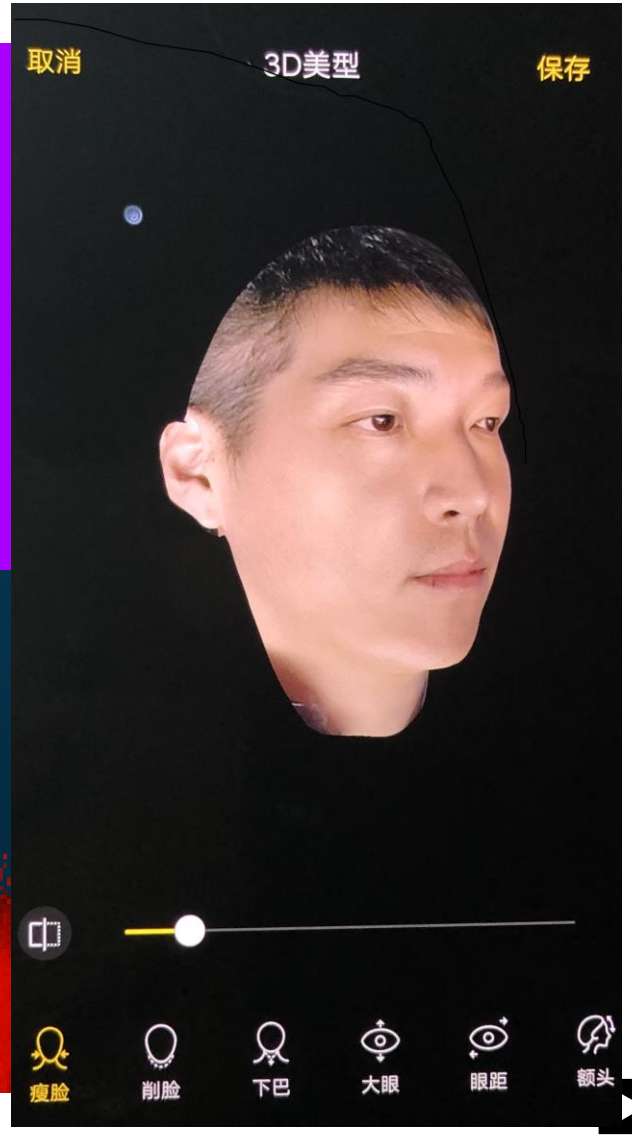
Interference Cancellation: Evaluation of Image Quality



ADI ToF depth image examples for facial recognition application







ANALOG DEVICES
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ADI ToF system level advantages analysis

	ADI TOF	Other TOF	Structure light
Spacial resolution	High	Low	Low
Module size	Small	Small	Big
Sensing range	Near to long 0.2m ~ 3m+, MP ready	Near to mid ~2m	Near
Proven calibration scheme	Yes, <30s per module	TBD	Complicated calibration scheme
Multiple system interference cancellation	Yes	TBD	No
Facial recognition performance	Proven FAR <1/1,000,000 Financial security level (3rd party algorithm)	TBD	TBD
Facial recognition speed	Best case <100ms Typical <350ms	TBD	>= 500ms

Objective performance test result

		Raw		Spatial Filter	
	Target Reflectivity	20%	90%	20%	90%
Distance					
1m	Depth Error	1.36%	0.71%	0.53%	0.73%
	Depth Noise Ratio	2.50%	1.16%	1.73%	0.79%
1.5m	Depth Error	0.91%	0.435	0.81%	0.57%
	Depth Noise Ratio	2.87%	1.34%	1.86%	0.93%
2m	Depth Error	0.47%	0.38%	0.60%	0.34%
	Depth Noise Ratio	3.30%	1.58%	2.18%	1.10%
2.5m	Depth Error	0.71%	0.36%	0.50%	0.40%
	Depth Noise Ratio	3.84%	1.76%	2.56%	1.17%
3m	Depth Error	0.42%	0.41%	0.39%	0.40%
	Depth Noise Ratio	6.50%	1.80%	3.70%	1.23%

TOF Hardware Roadmap
- All hardware can be promoted as a final product

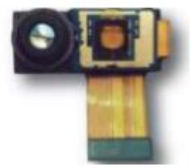
Q1 2019 | Q2 2019 | Q3 2019 | Q4 2019 | 2020

Pico

DCAM710
USB 2.0
DEPTH OUT ONLY
61 x 59 FOV
69mm x 25mm x 21.5mm
5 Meters
10 Meter Option
Recommended for new designs.
1 - $199

FOR INTRO / DEMO:
ADI WILL ISSUE FREE TO FAE FOR NEW OPPS
CUSTOMERS CAN BUY ONLINE
CONTACT: COLM SLATTERY

Pico



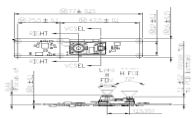
MIPI INTERFACE
DEPTH OUT ONLY
Narrow FOV
60mm*28mm*11mm
6 Meter Range

AVAILABLE FOR EVALUATION NOW

TOF Modules for Customers

Chicony

ETHERNET
USB
WIFI
Wider FOV
5 Meters
AVAILABLE FOR SALE FEB 2019
1 - $399
EDGE NODE PROCESSOR



MIPI VERSION
1 -$ 139
USB VERSION
1 - $159

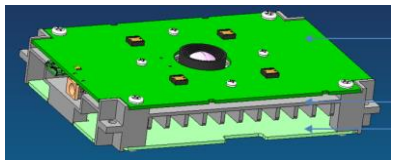
AVAILABLE FOR SALE FEB 2019

ANALOG DEVICES

96 TOF PLATFORM
QUALCOMM SNAPDRAGON

Q2/Q3 RELEASE

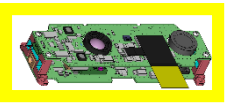
IN DEFINITON WITH PICO



INDUSTRIAL MODULE
USB & ETHERNET
61 x 59 FOV
5 Meters
3rd Party SDK
CAN BE SOLD WITH/WITHOUT HOUSING.

EST SAMPLES TBD
EST RELEASE

TOF SAFETY MODULE.
IN DEFINITION WITH 3RD PARTY



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