ADI 3D DEPTH SENSING
3D Depth Mapping

- Enables the user to get a human-scale understanding of its environment in the 3\textsuperscript{rd} dimension - i.e., it would make the camera aware of its surroundings in terms of \textit{how far away} the objects are as well as the \textit{actual mass} or \textit{scale} of each of those objects.

- Example: which pole is closest to the camera?
Depth Maps

Photographed Image

Distance Image

Far
Near
3D Depth Mapping Use Cases

- SLAM (Simultaneous Location and Mapping)
- Gesture Control
- Object Avoidance
- DMS / Passenger monitoring
- People Counting
- 3D scanning
- Safety / Proximity Sensing

ADI Proprietary Information
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.)

By 2020, ~$2B revenue expected from 3D imaging / sensing devices from non-consumer, non-automotive markets
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
1. Transmit IR optical pulse
2. Synchronously receive the optical reflection
3. Measure the time delay between the Tx and Rx pulses: \[ T_Z = \text{Time-of-Flight} \]
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 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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>ADDI9035</th>
<th>System Level advantage</th>
</tr>
</thead>
</table>
| 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

Spectrum of Sunlight

Wavelength

Photon Flux (%)

800 900 1000 1100 1200

RGB

CMOS TOF

Structured Light

ADI TOF CCD

14 ADI Proprietary Information
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

![Graph showing the effect of number of interfering cameras on relative jitter of depth measurement.](image)

- **Algorithm disabled**: Relative Jitter rises significantly with the number of interfering cameras.
- **Algorithm enabled**: Relative Jitter remains low and constant, indicating effective interference cancellation.
- **Baseline jitter measurement**: Normal mode, no interferers, showing minimal variation.

Number of interfering cameras in the same environment:

- 0
- 1
- 2
- 3
- 4
- 5

Relative Jitter of Depth Measurement (%)

0, 2, 4, 6, 8, 10, 12, 14, 16
ADI ToF depth image examples for facial recognition application
## ADI ToF system level advantages analysis

<table>
<thead>
<tr>
<th></th>
<th>ADI TOF</th>
<th>Other TOF</th>
<th>Structure light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacial resolution</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Module size</td>
<td>Small</td>
<td>Small</td>
<td>Big</td>
</tr>
<tr>
<td>Sensing range</td>
<td>Near to long 0.2m ~ 3m+, MP ready</td>
<td>Near to mid ~2m</td>
<td>Near</td>
</tr>
<tr>
<td>Proven calibration scheme</td>
<td>Yes, &lt;30s per module</td>
<td>TBD</td>
<td>Complicated calibration scheme</td>
</tr>
<tr>
<td>Multiple system interference cancellation</td>
<td>Yes</td>
<td>TBD</td>
<td>No</td>
</tr>
<tr>
<td>Facial recognition performance</td>
<td>Proven FAR &lt;1/1,000,000 (third party algorithm)</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Facial recognition speed</td>
<td>Best case &lt;100ms Typical &lt;350ms</td>
<td>TBD</td>
<td>&gt;= 500ms</td>
</tr>
</tbody>
</table>
### Objective performance test result

<table>
<thead>
<tr>
<th>Distance</th>
<th>Raw Target Reflectivity</th>
<th>20%</th>
<th>90%</th>
<th>Spatial Filter Target Reflectivity</th>
<th>20%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m</td>
<td>Depth Error</td>
<td>1.36%</td>
<td>0.71%</td>
<td>0.53%</td>
<td>0.73%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Noise Ratio</td>
<td>2.50%</td>
<td>1.16%</td>
<td>1.73%</td>
<td>0.79%</td>
<td></td>
</tr>
<tr>
<td>1.5m</td>
<td>Depth Error</td>
<td>0.91%</td>
<td>0.435</td>
<td>0.81%</td>
<td>0.57%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Noise Ratio</td>
<td>2.87%</td>
<td>1.34%</td>
<td>1.86%</td>
<td>0.93%</td>
<td></td>
</tr>
<tr>
<td>2m</td>
<td>Depth Error</td>
<td>0.47%</td>
<td>0.38%</td>
<td>0.60%</td>
<td>0.34%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Noise Ratio</td>
<td>3.30%</td>
<td>1.58%</td>
<td>2.18%</td>
<td>1.10%</td>
<td></td>
</tr>
<tr>
<td>2.5m</td>
<td>Depth Error</td>
<td>0.71%</td>
<td>0.36%</td>
<td>0.50%</td>
<td>0.40%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Noise Ratio</td>
<td>3.84%</td>
<td>1.76%</td>
<td>2.56%</td>
<td>1.17%</td>
<td></td>
</tr>
<tr>
<td>3m</td>
<td>Depth Error</td>
<td>0.42%</td>
<td>0.41%</td>
<td>0.39%</td>
<td>0.40%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Depth Noise Ratio</td>
<td>6.50%</td>
<td>1.80%</td>
<td>3.70%</td>
<td>1.23%</td>
<td></td>
</tr>
</tbody>
</table>
TOF Hardware Roadmap
- All hardware can be promoted as a final product

Q1 2019

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

Q2 2019

MIPI INTERFACE
DEPTH OUT ONLY
Wider FOV
60mm*28mm*11mm
5 Meters
AVAILABLE FOR SALE FEB 2019
1 - $399

EDGE NODE PROCESSOR

Q3 2019

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

AVAILABLE FOR SALE FEB 2019

TOF Modules for Customers

Q4 2019

96 TOF PLATFORM
QUALCOMM SNAPDRAGON

2020

TOF SAFETY MODULE.
IN DEFINITION WITH 3RD PARTY

IN DEFINITION 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

96 TOF PLATFORM
QUALCOMM SNAPDRAGON

2020

TOF SAFETY MODULE.
IN DEFINITION WITH 3RD PARTY

IN DEFINITION 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