

Webinar

Beyond 2D: Unlocking Robotic Environmental Awareness with 3D ToF & RGB Sensor Fusion

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pmd
IMAGINE YOU CAN

Infineon

Webinar Content

1. Time-of-Flight introduction
2. The start into Robotics: ToF in Robotic Vacuum Cleaner
3. A new REAL3™ ToF product member!
4. The journey to Humanoids: Application use-cases
5. pmd's real world example: 2D+3D fusion camera
6. The power of AI processing
7. Summary

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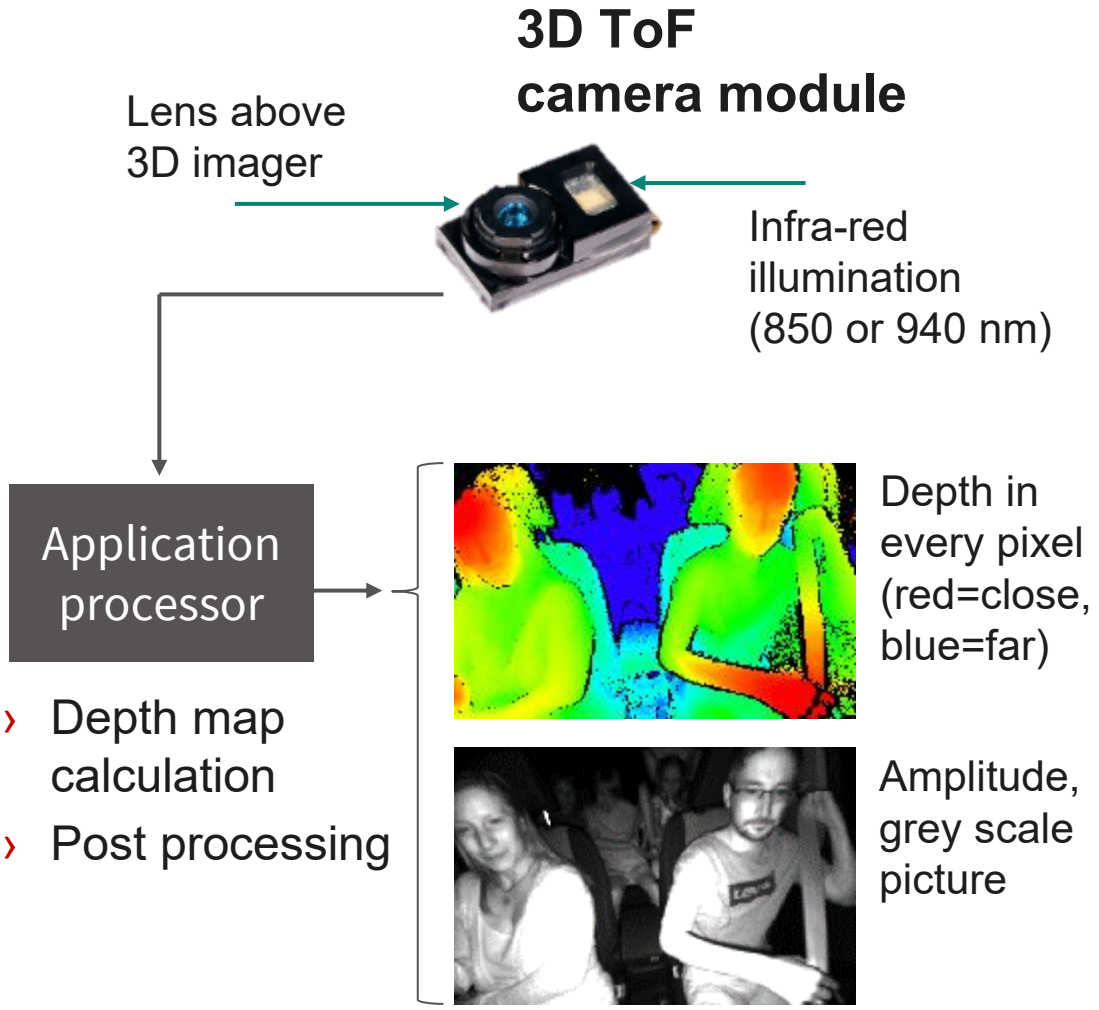
3D iToF provides most powerful data of the surrounding – Distance measurement and 2D-IR image simultaneously



Indirect Time-of-Flight (iToF) in a nutshell:

- Camera based technology
- Sending out active infrared light (VCSEL)
- Comparing transmitted with reflected signal
- Depth map is calculated out of the phase shift

What do I get? **the iToF benefits**

- **High resolution depth** map of the environment
- Distance information in every pixel and **2D grey scale picture simultaneously**
- In **all light conditions**: darkness and strong sun

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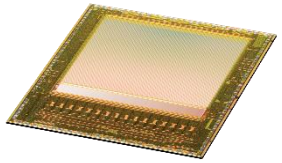
REAL3™ Time-of-Flight

Long history of successful product launches in multiple markets



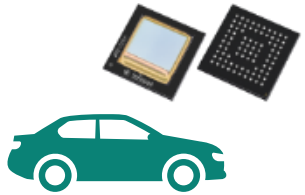
REAL3™ by Infineon



Security



AR



Automotive



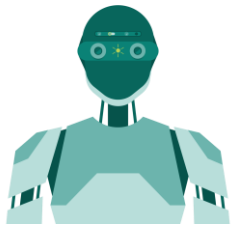
Lawn Mower



Smart lock



Vacuum Cleaner



Robotics

2013 — 2016 — 2020 — 2026

pmd Infineon

Infineon and **pmd** jointly developing ToF imager since 2013











Smart Phones (rear & front)

>28 million imager sold // 6th generation of pixel design

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Hybrid Time-of-Flight in Robot Vacuum Cleaner



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Hybrid Time-of-Flight (hToF)

Two-in-One: dual illumination for SLAM + Obstacle Avoidance





Dual-camera RVC:
- front: hToF with flood + spot illumination
- rear: spot ToF only

Hybrid time of flight combines the benefits of high-resolution flood illumination and precise, MPI-free spot illumination in a single small form factor 3D iToF camera

Flood: Generating a high-resolution 3D depth map. Ideal for advanced obstacle avoidance

Spot: Precise spot projection generates high accuracy long range depth points for SLAM and 3D mapping

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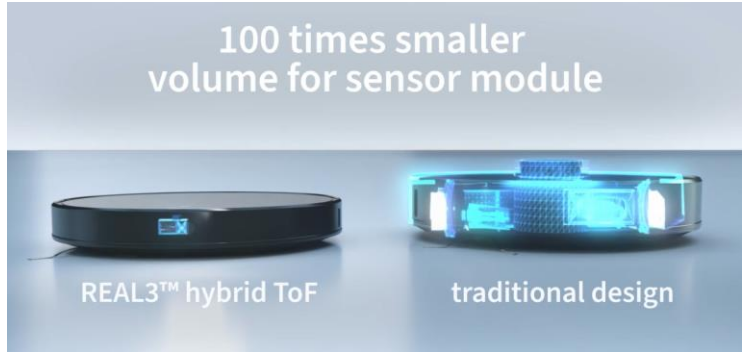
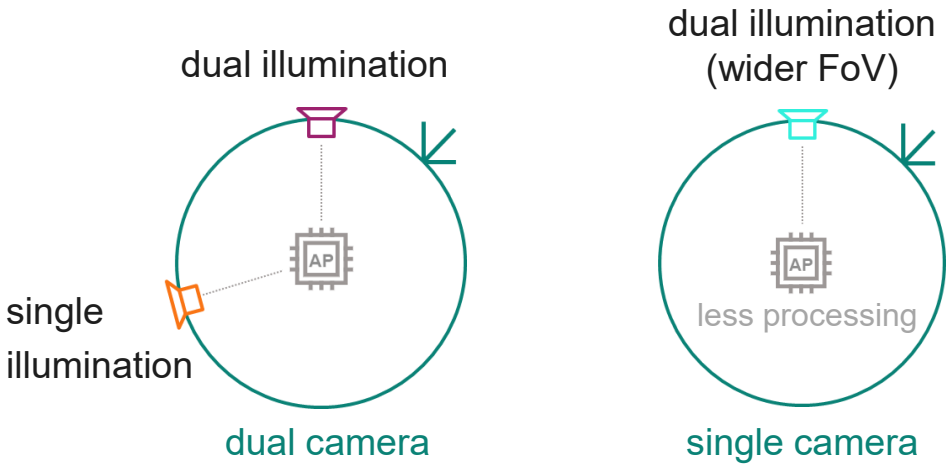
Why ToF in a robot vacuum cleaner?

- **Proven** for accurate and robust SLAM & obstacle avoidance
  → Camera module with dual-illumination technology (hToF)
- Up to 100 times smaller than traditional LDS
  → **free up space for innovation and customer value**
    - slimmer designs
    - adding a robot arm
    - include mop cleaning at the robot
    - bigger dust container
  → simplified product design & manufacturing
- **Reliable** technology: no moving parts
- **Scalable** solution for all price segments
  → dual camera or single camera
  → single or dual illumination // spot // flood // line laser
  → 2D + 3D camera fusion





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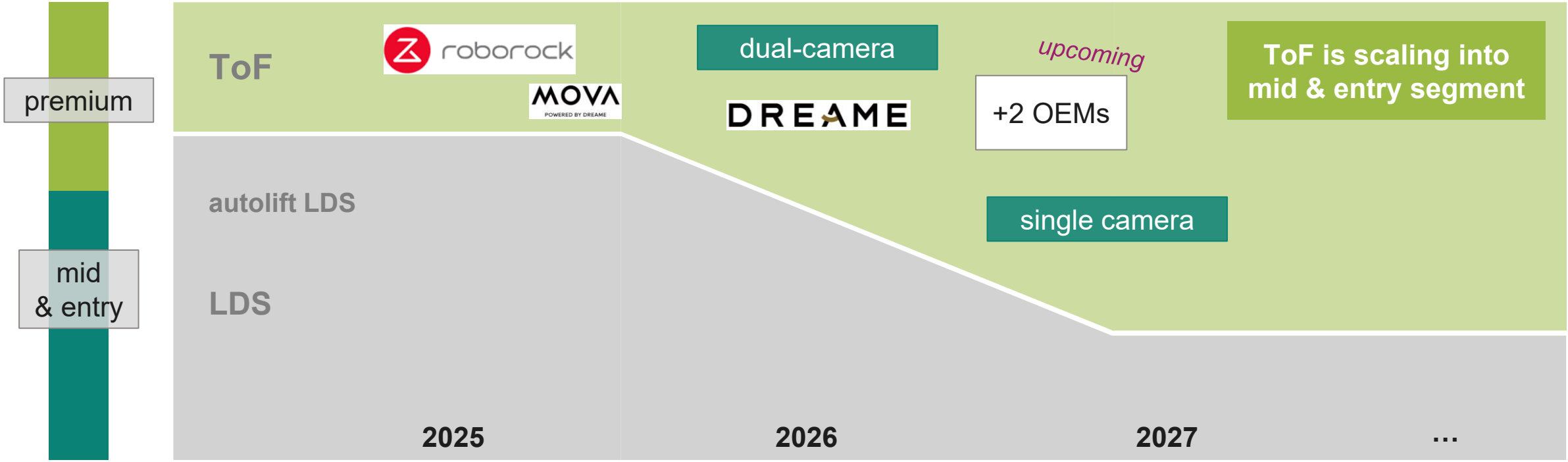
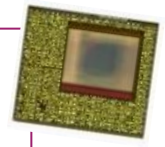
RVC's: ToF successfully launched in first premium models

Cost down roadmap to use ToF in all RVC model segments



- Infineon supports cost down roadmap to replace traditional LDS solutions
  - Hybrid Time-of-Flight (one imager + dual illumination)
  - Dual- or single-camera per robot depending on requirements
  - New optimized imager for line-laser illumination

Infineon to support cost down with **optimized imager variant IRS2875R**



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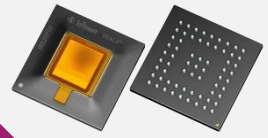
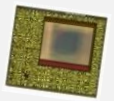
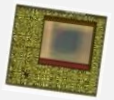
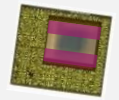
Infineon REAL3™ ToF imager & VCSEL driver portfolio

Leading position in the industry meeting multiple application requirements

	Automotive	Consumer				new
	SIL-2 support  ISO 26262 compliant					 QS: available SOP: 08/2026
Imager	**IRS2877A(S)**	**IRS2976C**	**IRS2877C**	**IRS2975C**	**IRS2875C**	**IRS2875R**
Resolution	**VGA** 640x480	**VGA** 640x480		**HQVGA** 240x180		**(HQVGA)** 240**x100**
Pixel / Tech.	7 µm / **EVO2+**	7µm / **EVO3**	7 µm / **EVO2+**	10 µm / **EVO3**	10 µm / **EVO2**	10 µm / **EVO2**
Special	ISO 26262 (ASIL-B)	increased QE	high-volume only	increased QE	-	reduced vertical ROI
Package	9x9 LFBGA-65	bare die // drop-in compatible		bare die // drop-in compatible		
VCSEL Driver	**IRS9103A** 	**IRS9102C** 				
Use-cases & Applications	• Driver authentication • DMS & OMS • Autonomous Parking • Industrial Robotic • **Functional Safety**	• Secure Face-ID • Robotics: **High-resolution** obstacle avoidance • Obstacle classification		• Robotics: navigation, SLAM & obstacle avoidance • IoT, Projectors		• Robot vacuum cleaner (RVC)
				• **Long range** / low power	• Standard	• Optimized for **line laser** illumination



› **Optimized imager + driver IC bundle: best in BOM, cost & size**

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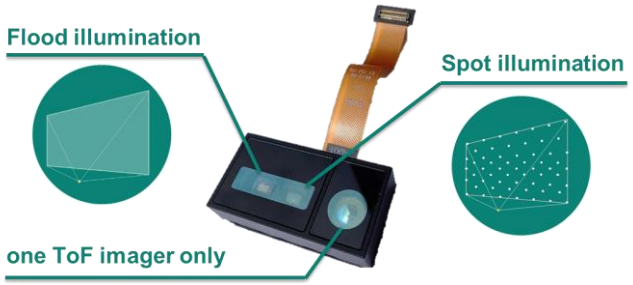
Precise Depth Measurement, Wide Range and Safety

3D ToF brings environmental awareness to any kind of robots

Robot Vacuum Cleaner & Lawn Mower



- Infineon **established hToF** in RVCs with market leading OEMs
- hToF: one camera module with dual illumination (flood + spot) enabling **SLAM and advanced Obstacle Avoidance**

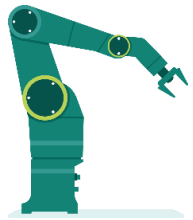


new

- Resolution **optimized imager** (IRS2875R)

Service Robots





Humanoid Robots



- **Re-use hToF** for SLAM and Obstacle Avoidance
- Dedicated solutions for other use cases
  - **Standard iToF** modules for face-ID or grappling control
  - **2D + 3D camera fusion** (RGB-D) + **AI processing**
  - **Safety** imager from Automotive (ISO26262, ASIL-B)

Strong partner eco-system with optimized robotic camera module offering

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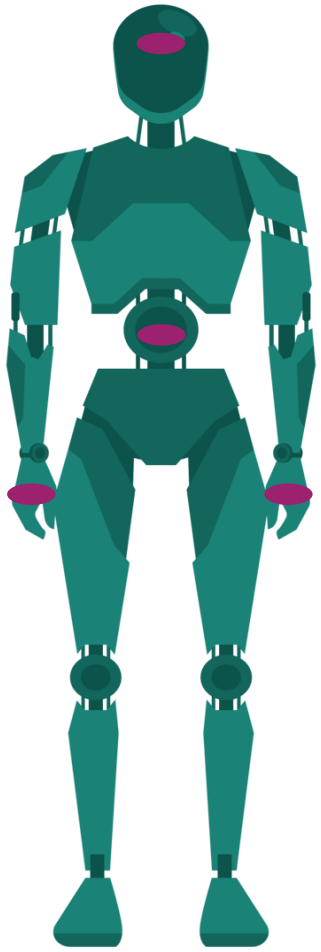
ToF for Humanoid Robotic
Use case examples

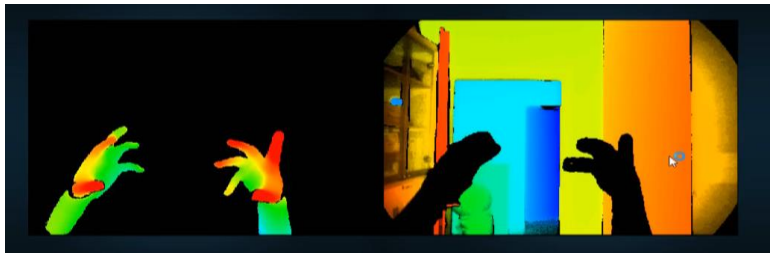


Head use cases / tasks
- User interaction & gesture
- Human presence detection
- Navigation & Mapping (SLAM)
- Obstacle avoidance (OA)
- Object detection/ classification

Hip use cases / tasks
- Navigation & Mapping (SLAM)
- SLAM
- Obstacle avoidance (OA)

Hand/Wrist use cases / tasks
- Grabbing control:
- Object detection & localization
- Shape estimation
- Pose and weight

Example of highly flexible imager configuration:
mixed mode for combined close- and long-range detection

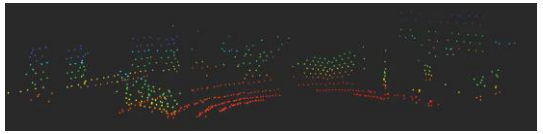


30fps close range 5fps long range

in all lighting conditions

hToF spot illumination: 3D point cloud for SLAM e.g 50 x 8 spots at 100° horizontal FoV <15m



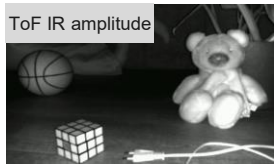


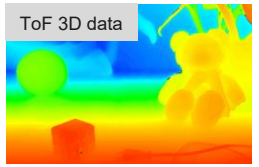
SLAM



ToF data: high resolution 3D pointcloud of the environment + simultaneous IR amplitude image









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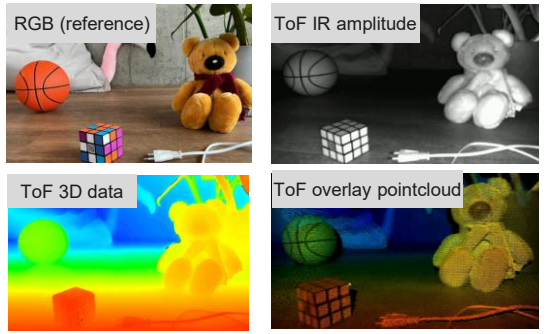
Reliable and robust obstacle detection and navigation in challenging conditions – Cobots and Mobile robots



Cobot use cases / tasks

- Pick and Place
- Grabbing control
- Shape estimation
- Pose and weight
- Invisible Fence
- Object detection/ classification

ToF data: high resolution 3D pointcloud of the environment + simultaneous IR amplitude image

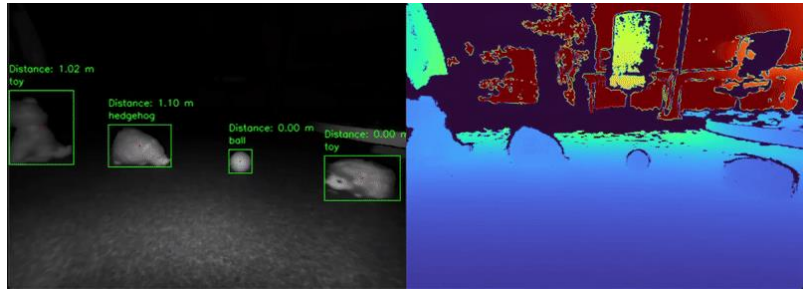




Mobile Robot use cases / tasks

- User interaction & gesture
- Human presence detection
- Navigation & Mapping (SLAM)
- Obstacle avoidance (OA)
- Object detection/ classification

Object detection and localization: high resolution 3D pointcloud of the environment + simultaneous IR amplitude image



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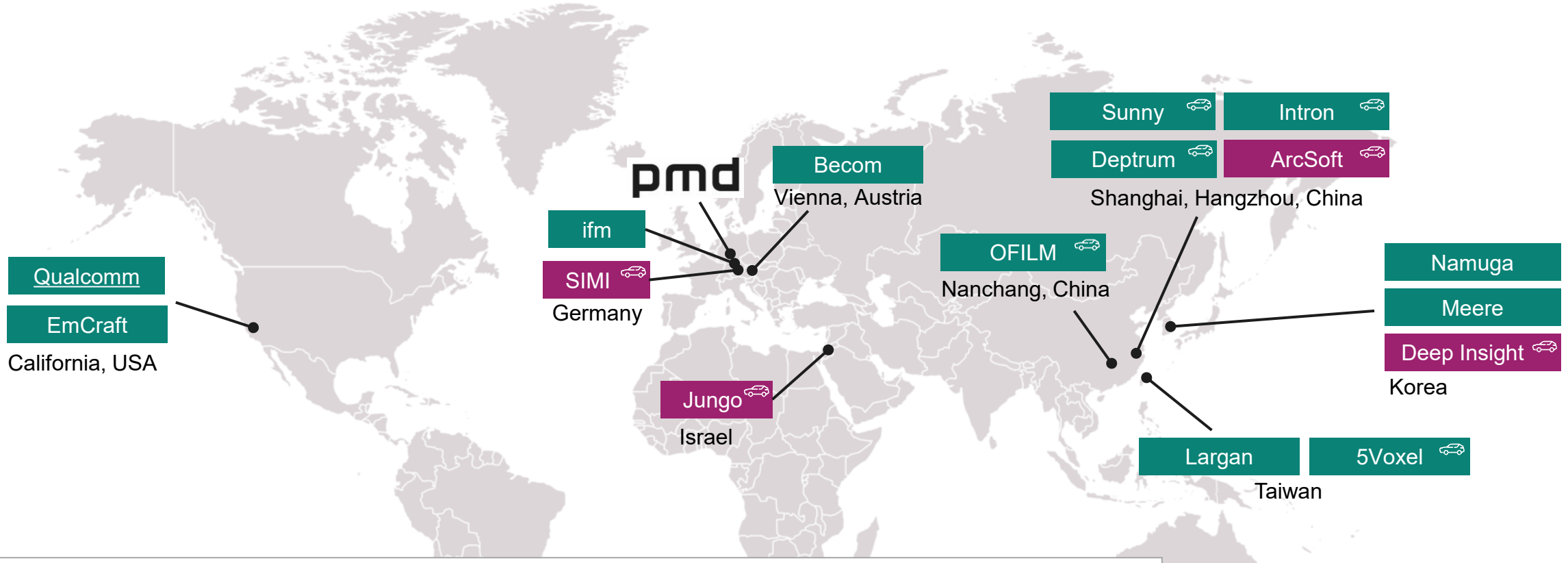
ToF Partner Network for Robotics, IoT and Automotive

Ease of integration with experienced partners



ToF solution	Depending on partner & use-case: – Camera HW / depth processing SW / design-house services / complete solutions
Software only	Application Software for REAL3™ ToF
	Consumer & automotive offering

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ToF Partner Network for Robotics, IoT and Automotive

Ease of integration with experienced partners



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The O3P:
Based on 10+ years of experience



The O3P:
Based on 10+ years of experience



O3P Key System Design Considerations:

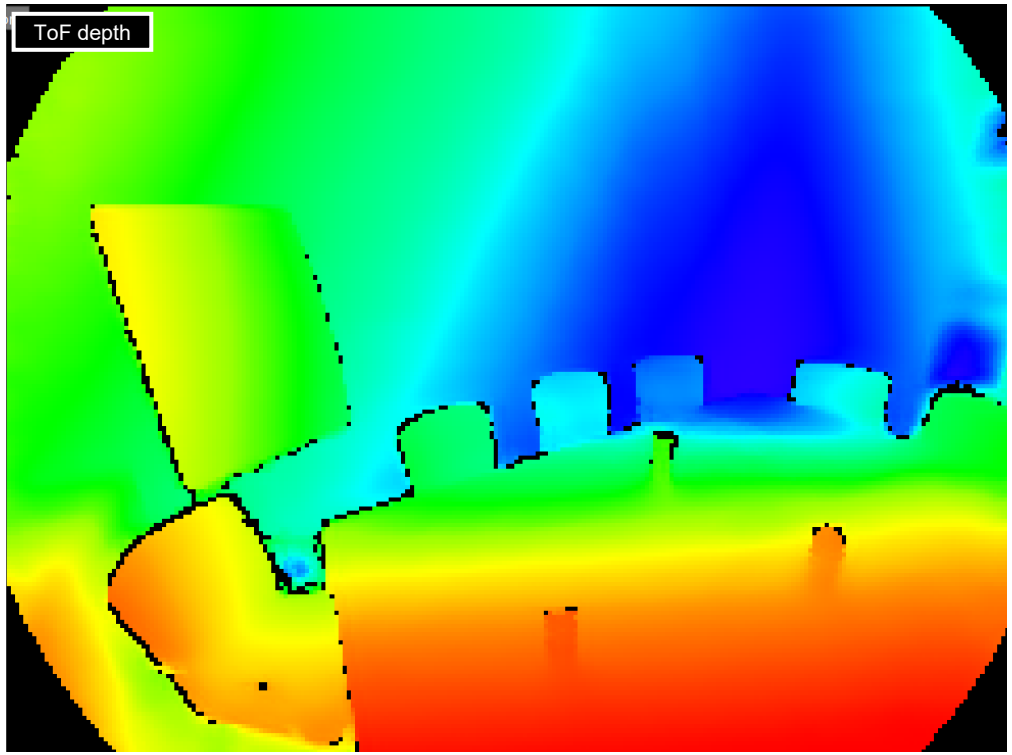
1. Reliable depth sensing
2. Sensor fusion is key
3. (Well) Synced sensors
4. Wider FoV is better
5. Range matters, real problems often closeby
6. Compute locally, minimal compute load for the host
7. Small form factor
8. No data is bad data

The O3P:
Realiable Depth Sensing, Sensor Fusion

- RGB and ToF are HW synced
- Most reliable depth sensing with HDR and Coded Modulation and Straylight Correction
- ToF is global shutter; delivers gray image in addition to depth data
- RGB is rolling shutter
- IMU delivers 3 axis angular velocity and 3 axis acceleration information

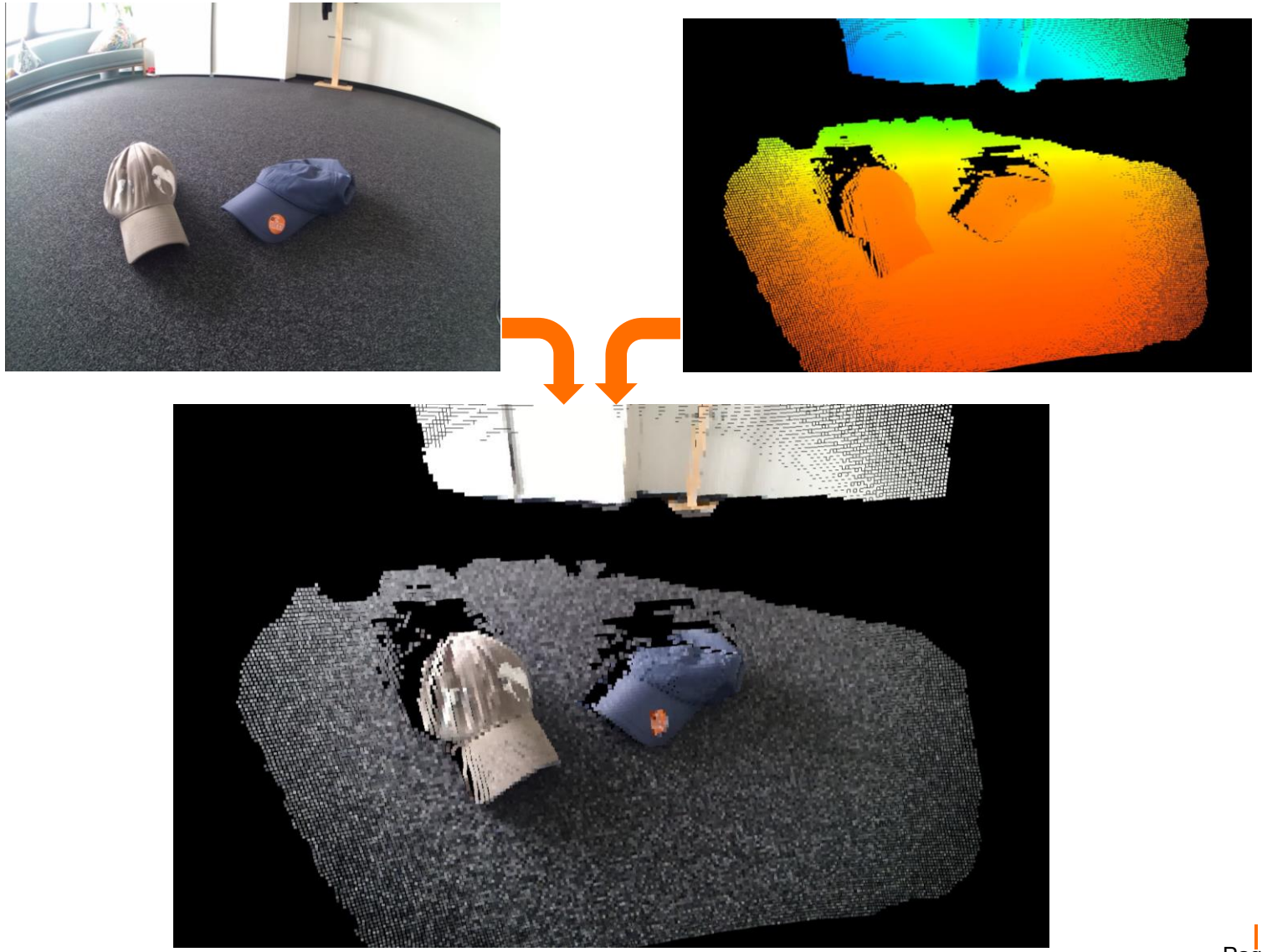






The O3P:
Realiable Depth Sensing, Sensor Fusion

- Intrinsics for RGB and ToF are stored in camera and available via API
- Intrinsics are determined per camera for highest data quality
- Timestamps for each data stream
- Fusion is achieved easily
  - Get (undistorted) XYZ points via API
  - Project into RGB image plane via intrinsics
  - Result: RGB value assigned to each 3D point cloud/depth pixel/IR

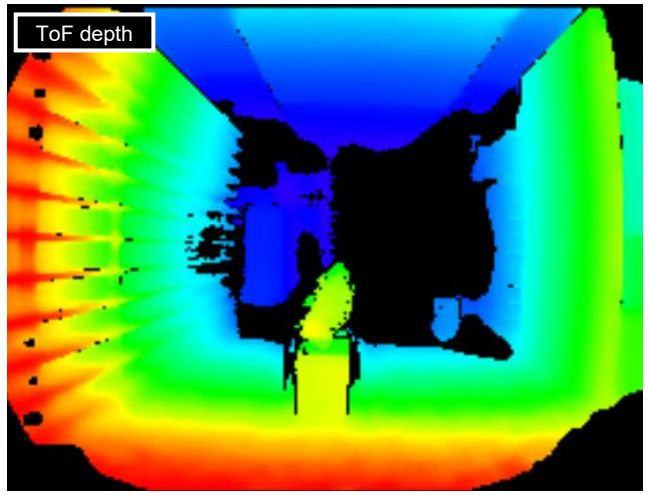


The O3P:
Synced sensors, wide FoV

Capturing **static objects** is important … but the **things which are moving** cause usually the real challenge

Example: Teddy bear falling into basket

- HW sync between RGB & ToF
- ToF is **global shutter**: minimal motion blur in gray image and depth image
- Bear falling is **capture consistently** mid-air in RGB and ToF





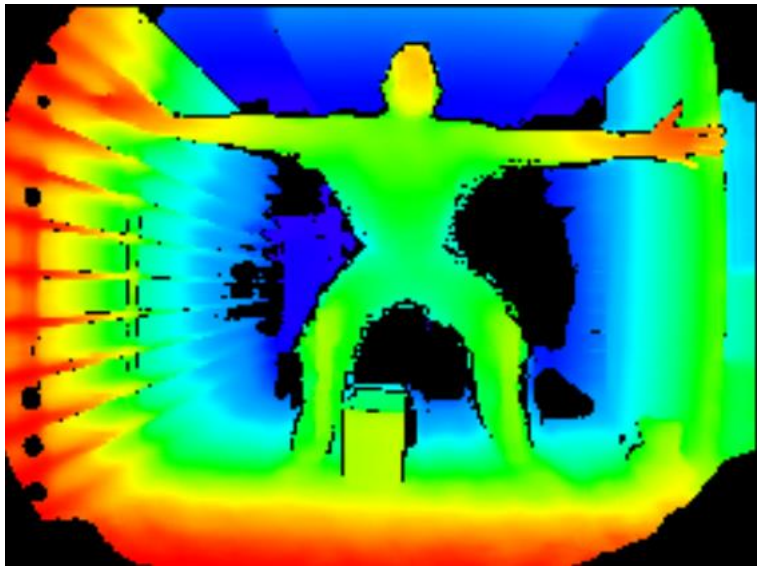


The O3P:
Synced sensors, wide FoV

Capturing with a wide FoV helps to not miss anything which is going on in front of your robot/device.

We created an extraordinary wide FoV of 105 x 86 degree.

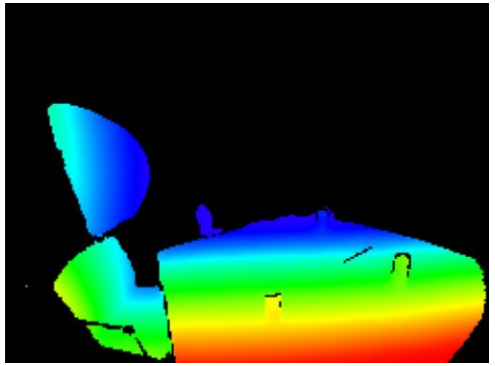
Field of view size (ToF)		
Distance [m]	**Width [m]**	**Height [m]**
1.00	2.65	1.87
2.00	5.31	3.73
3.00	7.96	5.60



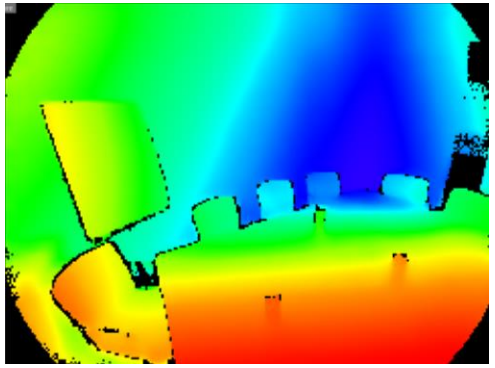


The O3P:
Presets – Managing flexibility of the device

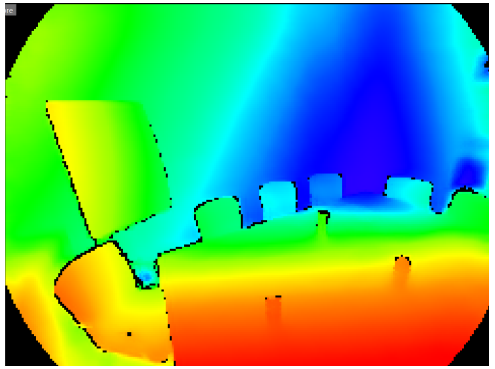




Preset: High Accuracy - Applies strict filtering to retain only the most reliable pixels, maximizing accuracy, 10fps, HDR



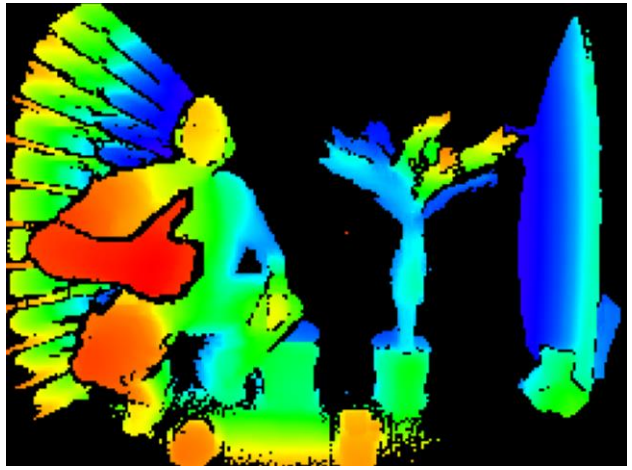
Preset: Moving Robot – Optimized for dynamic environments, enabling robust perception for robot navigation, 15fps, HDR



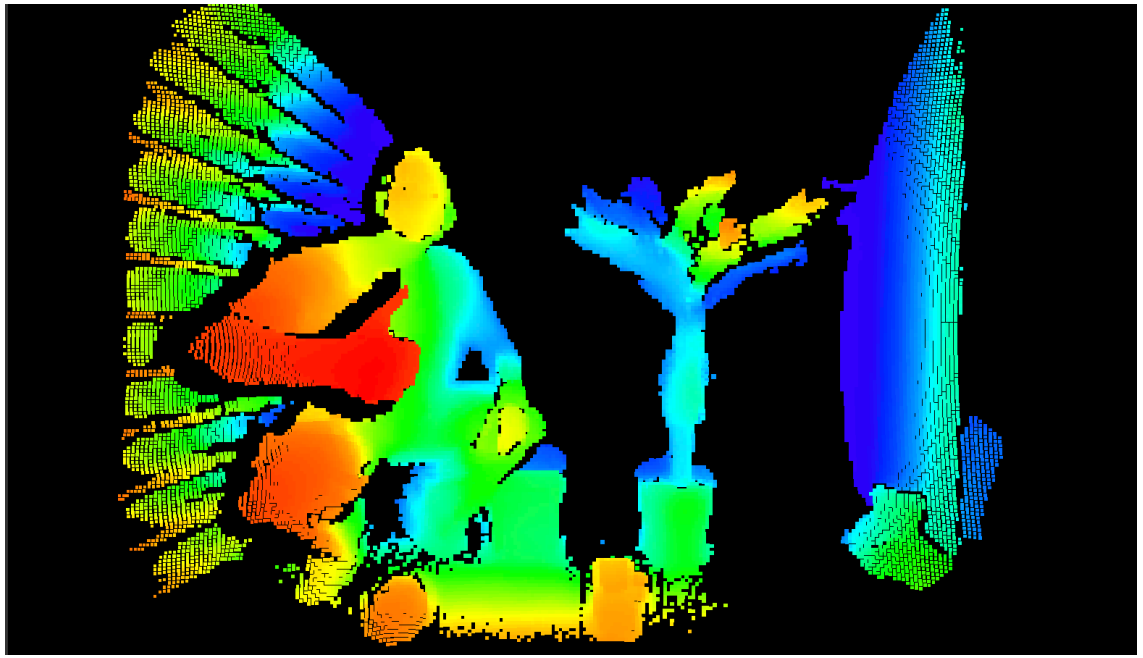
Preset: High Density Pointcloud – Minimizes filtering to preserve as many measurements as possible, increasing point density, 5fps, HDR

The O3P:
Presets – Managing flexibility of the device

- Factory presets are stored on camera and always available
- User/Developer can define own parameter set and create custom preset on host and use this via API/Viewer
- User/Developer can save current config and set this as default preset (stored in camera)
- Switching between presets is possible on-the-fly and takes a few 100 ms







The O3P:
Local compute, API, Code examples

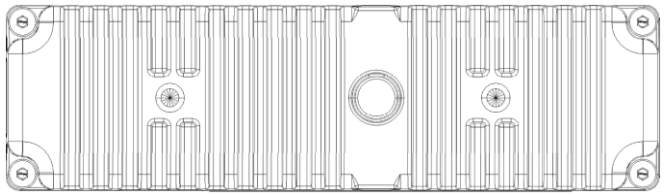
- Code examples will cover:
  - DeviceInfo : Shows how to read out the basic device information
  - Hello : Simple data readout example
  - Measure : Measure the distance between 2 points
  - Motion : Shows how to work with the IMU
  - MultiDevice : How to work with multiple cameras
  - OpenCV : How to use OpenCV with our data
  - Options : How to use the O3P Options interface
  - Pointcloud & Fusion : How to get the pointcloud, do the RGB alignment and visualize it
  - Recording : How to record data
  - ROS : ROS 1/2 node

```cpp
o3p::Pipeline pipe;
o3p::PipelineProfile profile;

try {
    profile = pipe.init(config);
} catch (std::exception &e) {
    return EXIT_FAILURE;
}

auto streams = profile.getStreams();

// Extract intrinsics and extrinsics from streams
o3p::Intrinsics tofIntrinsics{}, rgbIntrinsics{};
o3p::Extrinsics tofToRgbExtrinsics;

for (auto &s : streams) {
    auto *vs = dynamic_cast<o3p::VideoStream *>(s.get());
    if (vs) {
        if (vs->streamType() == o3p::O3P_STREAM_DEPTH) {
            tofIntrinsics = vs->getIntrinsics();
            tofToRgbExtrinsics = vs->getExtrinsics();
        } else if (vs->streamType() == o3p::O3P_STREAM_COLOR) {
            rgbIntrinsics = vs->getIntrinsics();
        }
    }
}

pipe.start();

while (true) {
    // Block program until frames arrive
    o3p::FrameSet frames = pipe.waitForFrames();

    // Try to get a frame of PointCloud
    auto pc = frames.getPointCloudFrame();

    // Align the color frame to the depth frame resolution
    o3p::alignColorToDepth(frames, tofToRgbExtrinsics, rgbIntrinsics, tofIntrinsics);

}
// Stop the pipeline
pipe.stop();
```

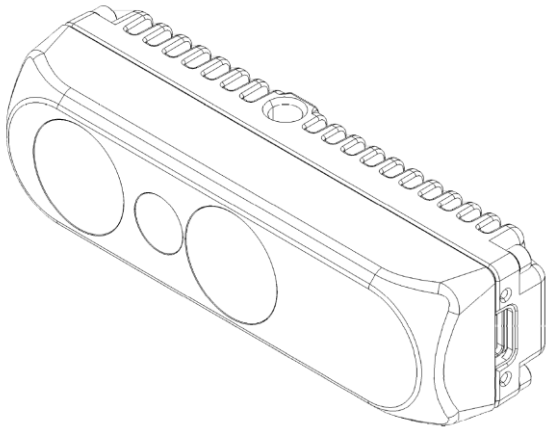
The O3P:
Form factor, connectors, mounting

90mm

25mm

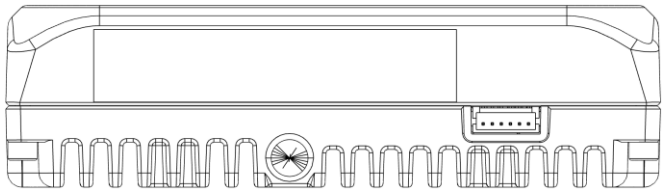


Back:
- 2 M3 x P0.5 mounts



Side:
- USB-C connector with 2 mounting screws for optimal mechanical stability
- Top: ¼ - 20 UNC mount

25mm



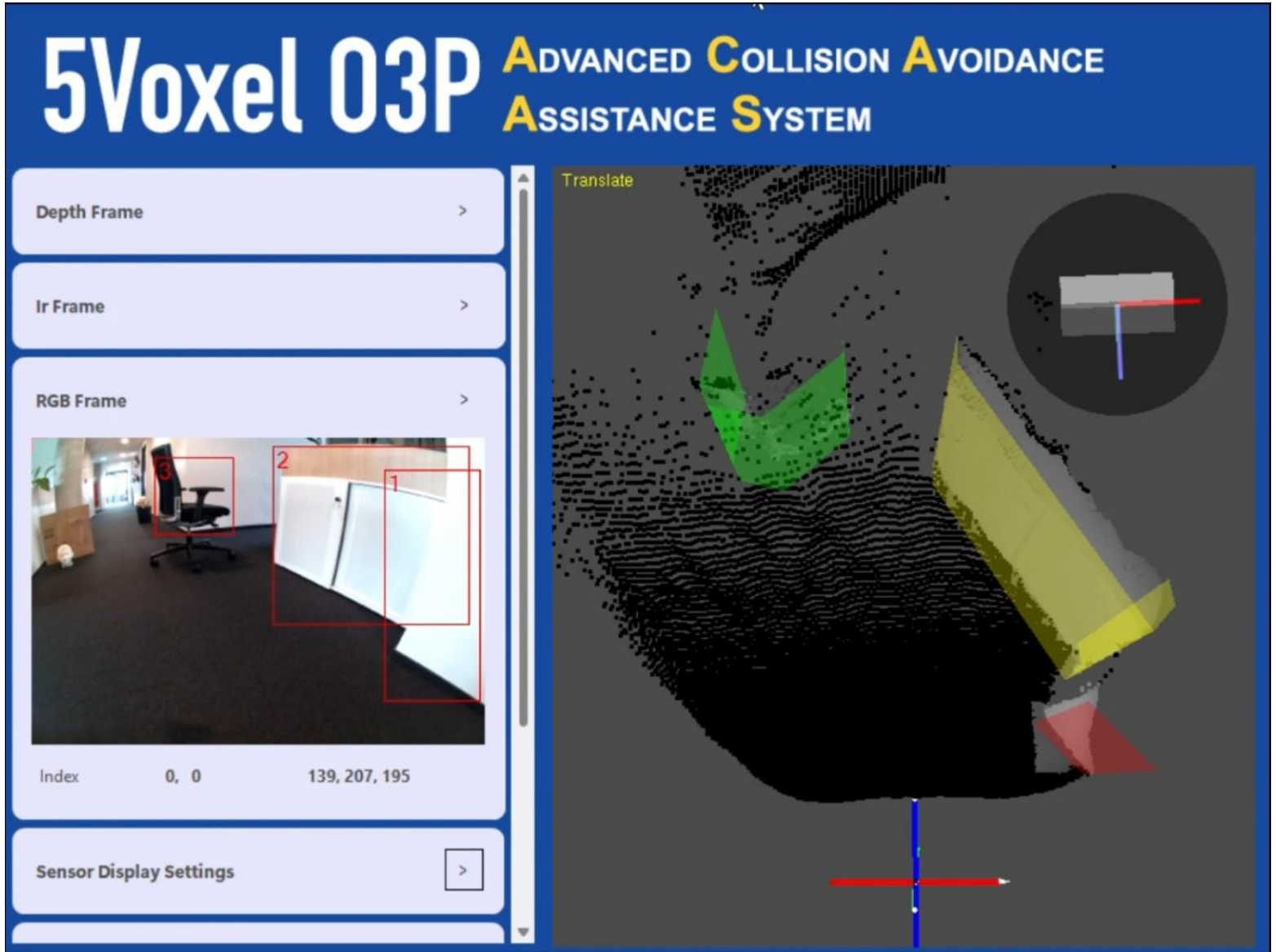
Bottom:
- Optional external power supply; only needed if host USB does not comply with USB 3.x specification
- ¼ - 20 UNC mount

The O3P:
In Action

Our partner 5Voxel has tested the O3P successfully for detection of objects for the avoidance of collisions:

- Colored „halos“ around detected objects in the point cloud (right image) indicate very close (red), close (yellow) and far away (green)
- Red boxes in RGB image mark the detected object as well for visual reference

https://www.infineon.com/partners/design-partner/5voxel



The O3P:
One more thing … AIDE

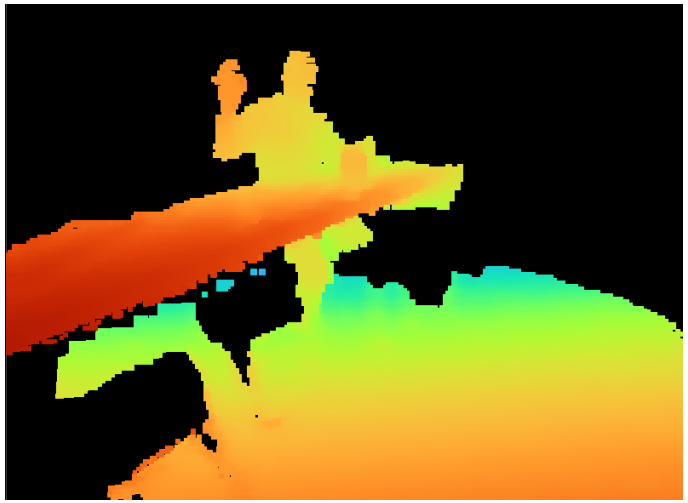
Some time ago we wondered:

- Can the **fusion of RGB and TOF be accomplished** in the camera in real-time?
- Can the **resolution of ToF be increased** by a fusion with RGB?
- Can **missing/wrong data** in the depth data be **recovered**?

The answers we found: Yes. Yes. And … Yes.

And we call it: **AIDE**.

AI Depth **E**nhancement.





Original depth data: ok … but can we make it better?

AIDE: AI Depth Enhancement
Edge AI for Enhanced 3D Perception

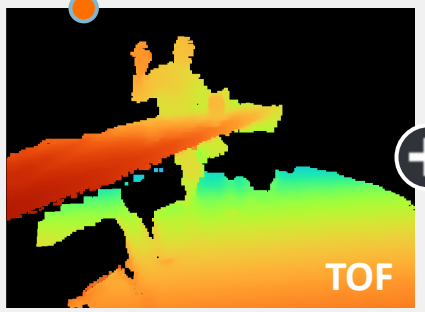


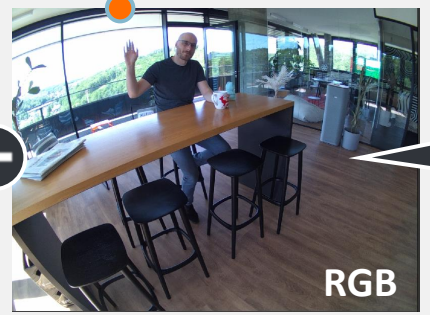
Better 3D Perception with AIDE

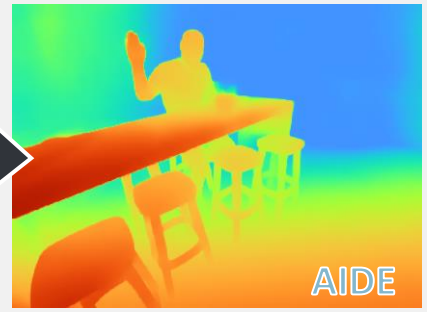
- Resolution increased 4x
- Denser, sharper, more complete depth maps
- Filled missing data (black or thin objects, sunlight, reflections)

Fusion on Edge with AIDE

- Compact Edge AI - local processing on small NPUs
- Better 3D perception without relying on cloud processing







Cloud AI
∞ TOPS

ChatGPT
Copilot

Powerful edge
100–500 TOPS



Edge SoC
50–80 TOPS



Entry-level AP
1 TOPS

AIDE: AI Depth Enhancement
Edge AI for Enhanced 3D Perception



Classic: XYZ projected into RGB

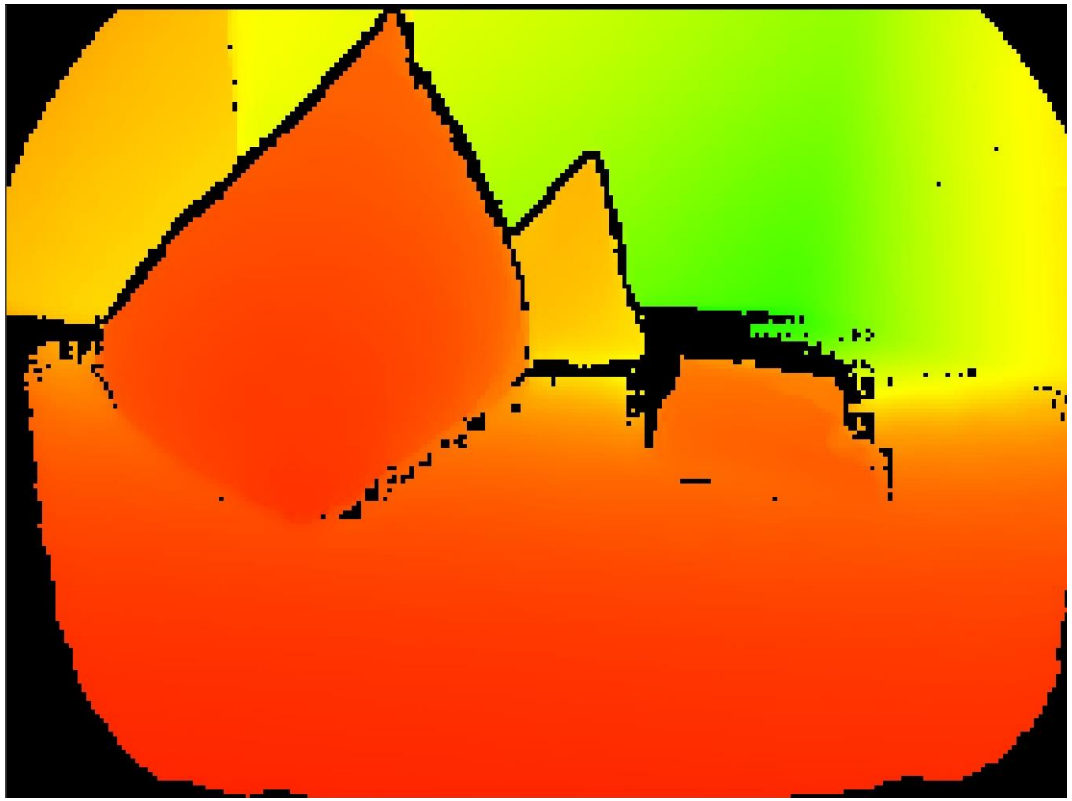


AIDE: XYZ projected into RGB

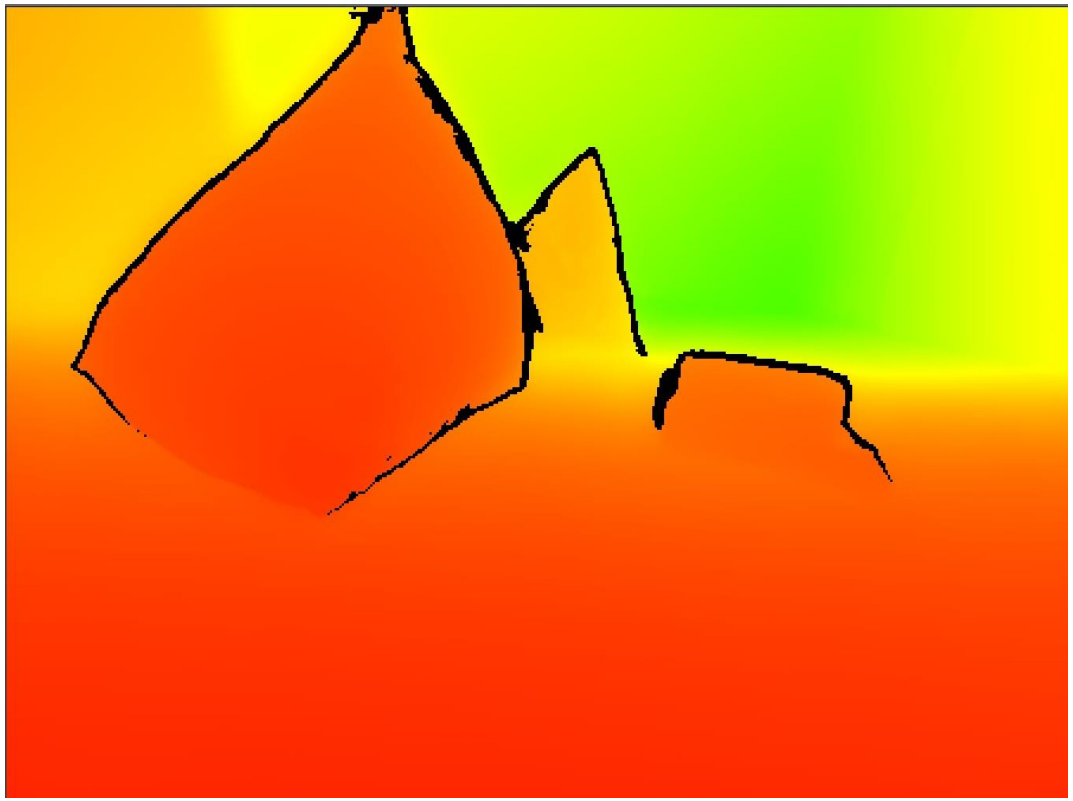


AIDE: AI Depth Enhancement
Edge AI for Enhanced 3D Perception

Classic



AIDE



AIDE enhances the native depth data, which …

AIDE: AI Depth Enhancement
Edge AI for Enhanced 3D Perception

Classic



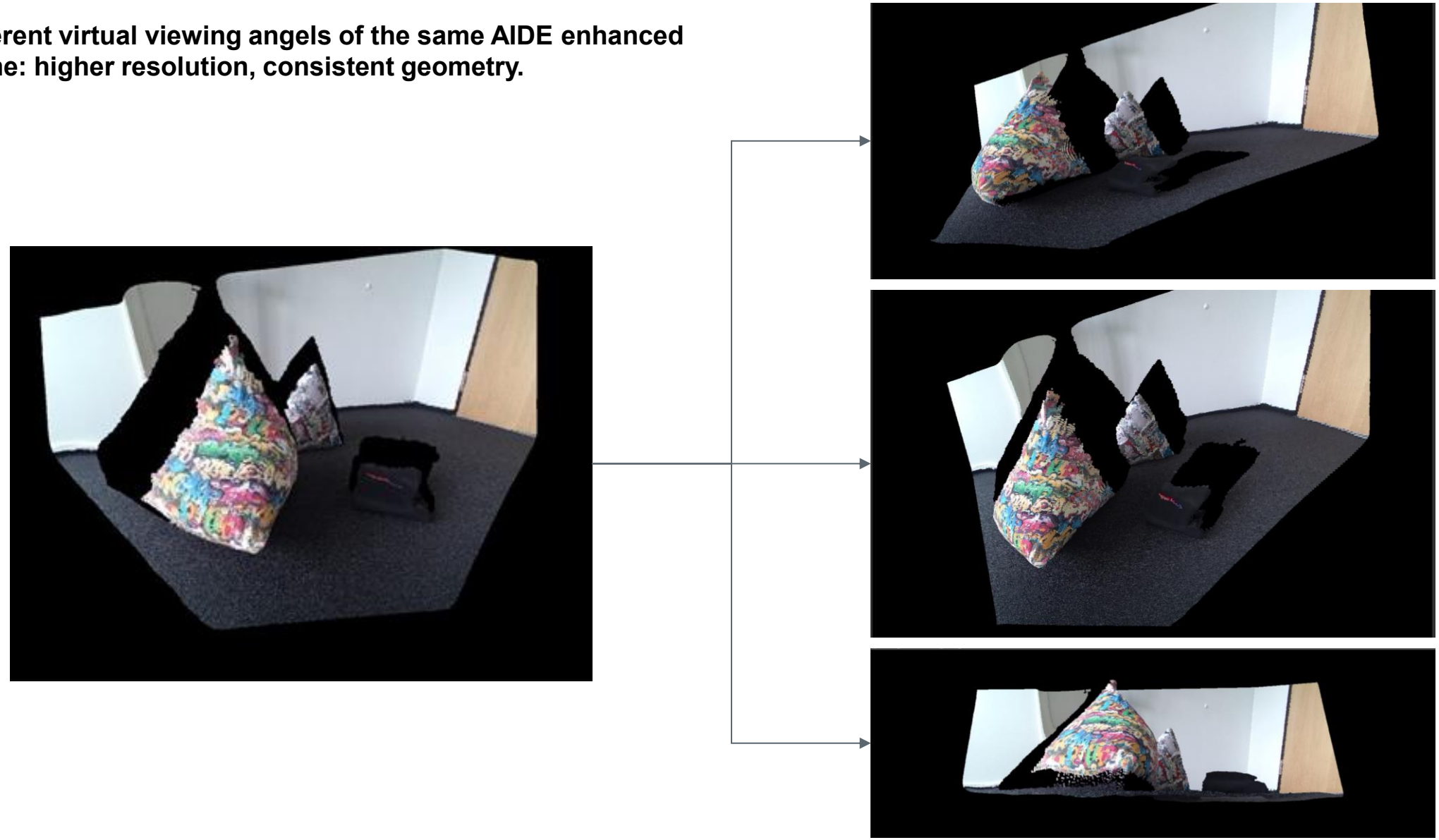
AIDE



… improves RGBD perception of environment.

AIDE: AI Depth Enhancement
Edge AI for Enhanced 3D Perception

Different virtual viewing angels of the same AIDE enhanced scene: higher resolution, consistent geometry.

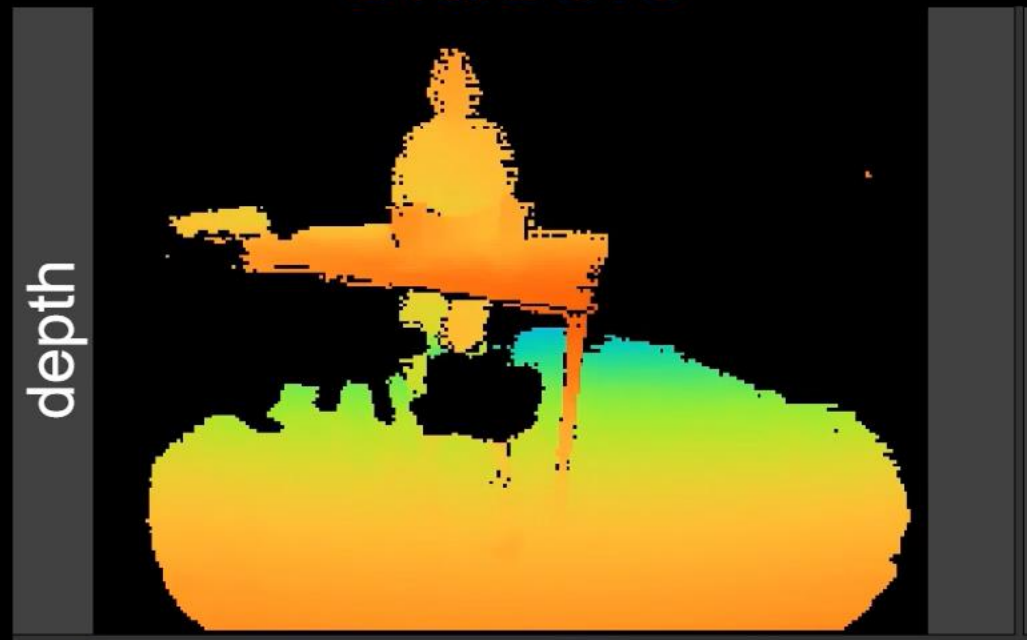


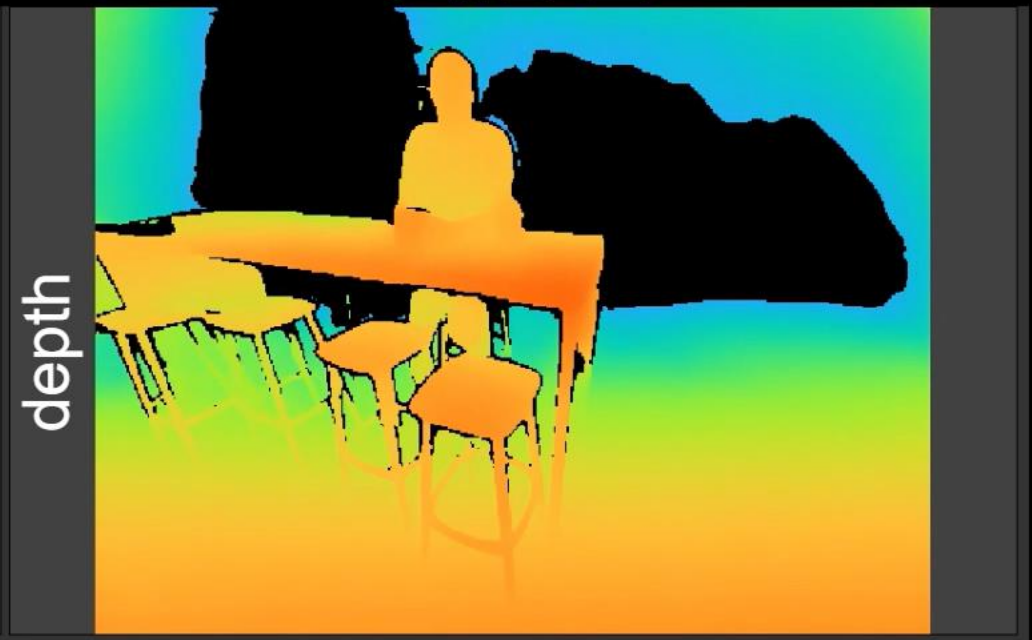
TOF:
Challenging to measure black objects (missing fine objects)

With our edge AI:
Pay attention to chair legs!

Classic

AIDE









Chair legs

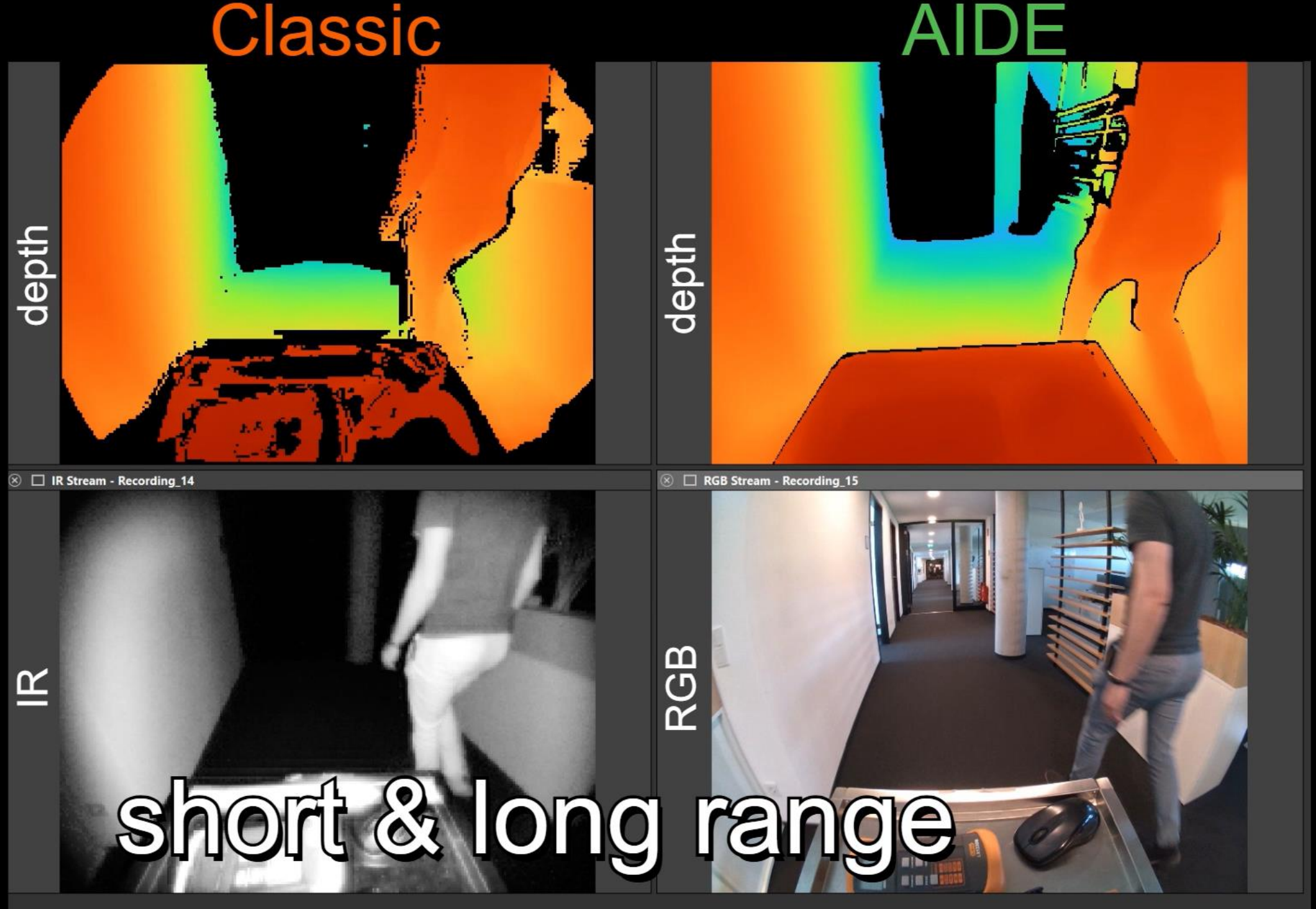
TOF:
Sunlight disturbs measurements (noisy or missing data)

With our edge AI:
Recovers missing regions in sunlight



TOF:
Some data is missing

With our edge AI:
Recovers missing data and extends measurement range



Summary



https://ifm.com/cnt/o3p

Infineon REAL3™ Time-of-Flight
Unlocking Robotic Environmental Awareness

Established iToF in Robot Vacuum Cleaner (RVC).

Scaling into lawn mover, service robots and industrial & humanoid robotics.

Bill of Material optimized ToF imager + VCSEL driver IC bundle.

Best in size, flexibility and performance at low power.

Strong partner network offering wide variety of ToF modules to meet different application requirements:

- The next level of performance: O3P from ifm/pmd.
- Unique 2D + 3D ToF fusion camera with AI processing.

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