S Series: dToF-Based RGBD Cameras

Technical Reference & Application Handbook

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Prepared by: MRDVS Technology

Content

Revision History

Rev. Date	Ver.	Edit by	Audit By	Revision Description
13-Jan-25	V1.0	Liping Wang	Ling Shi	Initial released
5-May-26	V2.3	Liping Wang	Ling Shi	Added Appendix E (Use Cases) and restructured Appendix D
8-May-26	V2.4	Ruiyang Liu	Liping Wang	Added Appendix D.2 3D Vision Sensors Selection Guide
6-Jun-26	V2.6	Liping Wang		Added Product Roadmap and Chapter 6, 7, 8 Algorithms Details, Test Data & Reference Downloads Link
12-Jun-26	V2.7	Liping Wang		Added .STEP file to different models

1. Product Overview

1.1 Introduction

The S Series is a family of compact, industrial-grade RGBD cameras built on dToF (direct Time-of-Flight) technology, providing synchronized RGB and depth data for mobile robot perception and depth sensing in demanding environments.

The series currently includes four models:

- S10: A compact industrial-grade RGBD camera providing synchronized depth and RGB data over a range of 0.3~8 meters. It features internal spatial and temporal alignment between depth maps and color images, supports multiple data streams (depth, intensity, RGB, point clouds, and processed obstacle avoidance results), and operates reliably indoors and outdoors under up to 100 KLUX ambient light. With low power consumption and frame rates up to 20 fps, the S10 is ideal for real-time responsive sensing and obstacle avoidance.
- S10 Ultra: A small-form-factor, wide-field-of-view, cost-effective industrial-grade RGBD camera that extends the sensing range up to 42 meters (0.2m~42m). In addition to core dToF capabilities, the S10 Ultra features RGB-D-IMU fusion with a built-in IMU (output at 200Hz), effectively supporting mainstream SLAM algorithms such as Fast-LIO, and LIVO (LiDAR-Inertial-Visual Odometry). It delivers spatially and temporally aligned RGB and depth data, supports software trigger, and is available in an MIPI module version for volume demand. The fully solid-state design (no moving parts) ensures enhanced vibration resistance and stability.
- S11: A high-cost-effectiveness, compact RGBD camera with an ultra-wide 140° HFOV, designed for obstacle avoidance at ranges up to 6 meters with ≤10 mm full-range accuracy. It supports USB, Ethernet, and MIPI (MIPI available for volume orders only), offering flexible connectivity for various integration needs. Compared to the S10, the S11 offers more flexible

interface options, slightly better accuracy, and a larger horizontal field of view (HFOV). However, its vertical field of view (VFOV) is smaller than that of the S10. The S11 provides higher cost-effectiveness. Therefore, if the VFOV meets the application requirements, the S11 is the primary recommendation.

- MIPI Module: To meet the lightweight, cost-effective, and easier integration demands for drones, lawn mower robotics, service robots, and consumer electronics, the S10 Ultra-MIPI and S11-MIPI modules are designed for direct connection to host processors via a compact MIPI CSI-2 interface (supporting NVIDIA Jetson, Qualcomm, NXP, Rockchip, and other platforms), eliminating the need for an external Ethernet controller. The modules deliver raw data output - including depth, IR amplitude, and optional RGB streams, making it ideal for high-volume embedded vision systems.

1.2 Product Status

1.2.1 S10

- Status: Launched in Q3 2025
- Certified: CE, Laser Safety Class 1, RoHS, REACH
- Availability: Available for immediate order

1.2.2 S10 Ultra

- Status: Pre-order
- Certification: In preparation; planned to be completed in Q3 2026
- Availability: Accepting pre-orders. First testing unit available in Q2 2026. Larger volumes require confirmation.

1.2.3 S11

- Status: Final retuning
- Certification: In preparation; planned to be completed in Q3 2026

- Availability: Accepting pre-orders. First testing unit available in Q2 2026. Larger volumes require confirmation.

1.3 Product Roadmap

In Q4 2026, we will launch the S20, a next-generation dToF depth camera based on 2D addressing technology, featuring ultra-wide FoV (180°), extended range up to 50 meters, improved accuracy ($1\sigma < 3$cm), and reduced jitter. Detailed specifications will be provided upon sample release.

Additionally, we are actively evaluating GMSL and M12 connector interfaces for future product variants. Depending on market feedback and customer requirements, we plan to release derivative models with these interfaces to better serve applications in humanoid robotics, rugged industrial, and high-reliability environments.

2. Specifications

Parameter	S10	S10 Ultra	S11
Laser Wavelength	940nm	940nm	940nm
Output Format	Depth/RGB/IR Amplitude Map	Depth/RGB/IR Amplitude Map	Depth/RGB/IR Amplitude Map
Depth Resolution & Frame Rate①	240 × 160 @Max 20fps (typ. 15fps)	240 × 160 @Max 10fps (typ. 10fps)	240 × 96 @Max. 15fps (typ. 10fps)
TOF FOV (H×V)	120° × 80°	120° × 80°	140° × 56°
RGB Resolution & Frame Rate①	1632 × 1224 @ Max. 20fps (typ. 15fps)	1280 × 1080 @ Max 10fps (typ. 10fps)	1280 × 1080 @ Max 15fps (typ. 10fps)
RGB FOV (H×V)	120° × 80°	120° × 110°	120° × 110°
Range	0.3~8m (90% reflectivity); 0.3~3m (5% reflectivity)	0.2~42m (90% reflectivity); 0.2~30m (5% reflectivity)	0.1~6m (10%-90% reflectivity), 100kLux
Accuracy②	≤3 cm	≤4 cm	±1 cm @ 2m; ±2 cm @ 6m
IMU	Not available	Built-in, 200Hz (Bosch BMI088)	Not available
Average Power Consumption	≤4W	< 9W	Typ. <4W Max. 13W
Dimensions (L×W×H)	80 × 37 × 25 mm	106 × 69 × 43 mm	90 × 25 × 25 mm
Weight	190 g	440 g	130 g
Power Supply	12~28V DC (±20%)	12~27V DC (±20%)	12~28V DC (±20%) 5V USB 3.0 (±20%)

Parameter	S10	S10 Ultra	S11
Interface	Ethernet	Ethernet	Ethernet/USB*
MIPI CSI-2 Available	No	Yes	Yes
IP Rating	IP54	IP67	IP54
Operating Temperature	-20°C~60°C	-20°C~75°C	-20°C~60°C
Storage Temperature	-40°C~85°C	-40°C~85°C	-40°C~70°C
Time Synchronization	PTP	PTP	PTP
SDK Support	C/C++/ROS1/ROS2	C/C++/ROS1/ROS2	C/C++/ROS1/ROS2
OS Compatibility	Windows 7/8/10/11, Linux, Arm Linux	Windows 7/8/10/11, Linux, Arm Linux	Windows 7/8/10/11, Linux, Arm Linux
Ambient Light Resistance	100 KLUX	100 KLUX	100 KLUX

Table 1 Product Specification Parameters

Note:

①*The typical (typ.) frame rate represents the recommended operating condition for optimal thermal and power performance. The maximum (max.) frame rate is technically achievable but may lead to increased power consumption and higher temperature rise. Operation at max. frame rate is not recommended for general use. If higher frame rates are required for a specific application, please contact MRDVS technical support for further evaluation.*

②*Accuracy may degrade with distance and depends on object reflectivity and surface roughness. All accuracy values reported in this document are based on 1σ (one standard deviation), representing the statistical variation measured under controlled laboratory conditions using a white wall target.*

3. Technology Overview: dToF vs. Stereo

3.1 How They Work & Accuracy Comparison

- dToF Camera: Measures distance by emitting light pulses and directly timing their round-trip flight. Every pixel returns a valid depth value regardless of surface texture or color. Provides consistent absolute accuracy throughout the specified working distance range. Near-field depth resolution is lower due to SPAD array density.
- Stereo Camera: Computes depth by triangulating corresponding features from two image sensors. Performance depends heavily on surface texture, lighting, and pattern richness. Achieves sub-millimeter accuracy at very close range (<0.5 m), but accuracy degrades beyond ~3 meters due to disparity error.

3.2 Application Scenarios

- dToF Camera: Reliable obstacle avoidance for a wide range of mobile robots, including AGV, AMR, cleaning robots, outdoor low-speed vehicles, and UAVs, as well as operator-assisted blind-spot detection on manned vehicles (e.g., forklifts). Performs reliably on low-reflective objects, uniform surfaces, and under outdoor lighting.
- Stereo Camera: 3D scanning, facial recognition, industrial inspection – best when scene texture is controllable.

A comprehensive comparison, including additional test scenarios, in-depth analysis, full reference data, and application-specific recommendations, is available Appendix: Application Notes - RGB-D Camera Comparison: MRDVS S11 vs. Intel RealSense D435.

4. Hardware Description

4.1 S10 Camera

4.1.1 Camera Interfaces

There are two interfaces on the S10 camera end: DC24V power interface, 100M Ethernet interface.

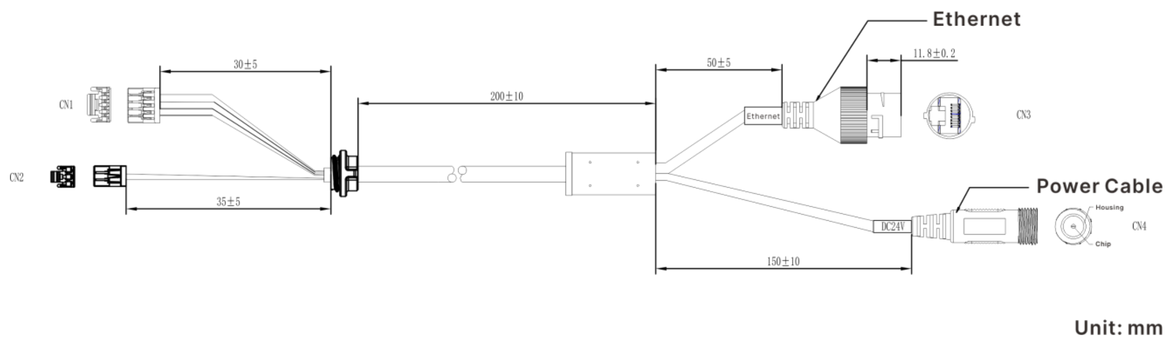

Figure 1 - S10 Camera Interface Diagram

4.1.2 Component Overview

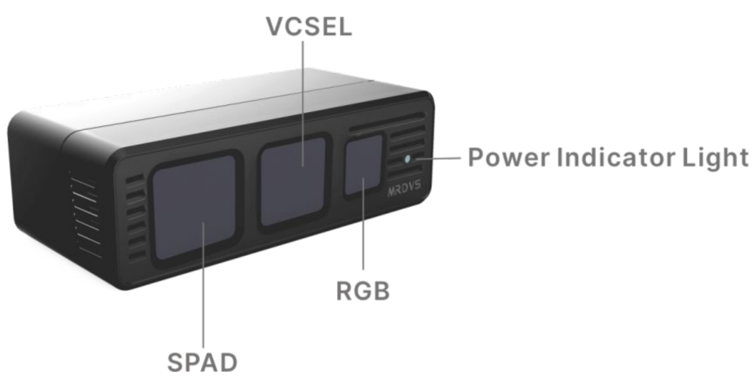

Figure 2 - Overview of S10 Camera

4.1.3 Mechanical Drawing

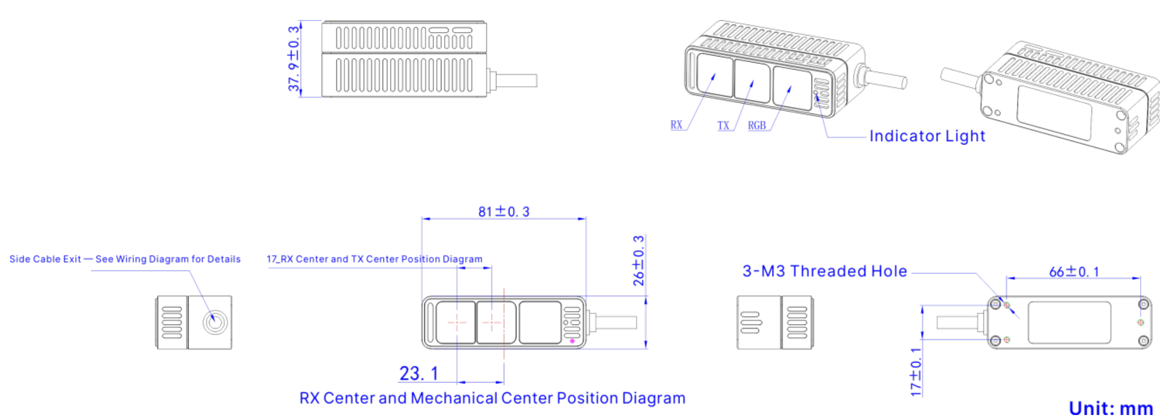

Figure 3 - S10 Camera Dimensions Diagram

4.1.4 Mechanical File Download

1) 3D Structure File - STEP: download

2) 2D Drawing: download

Important: *Please confirm the latest dimensions and documents with us prior to integration.*

4.1.5 Photo of the physical product

Figure 4 - S10 Photography

4.2 S10 Ultra Camera

4.2.1 Camera Interfaces

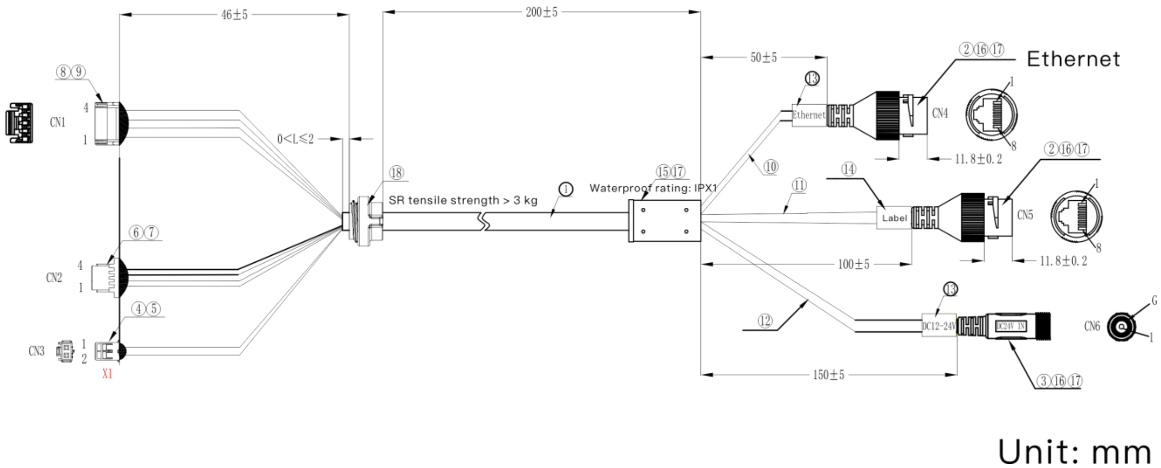

Figure 5 - S10 Ultra Camera Interface Diagram

4.2.2 Component Overview

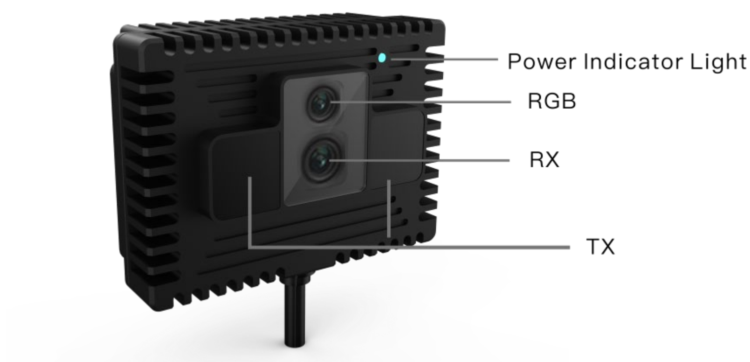

Figure 6 - Overview of S10 Ultra Camera

4.2.3 Mechanical Dimensions

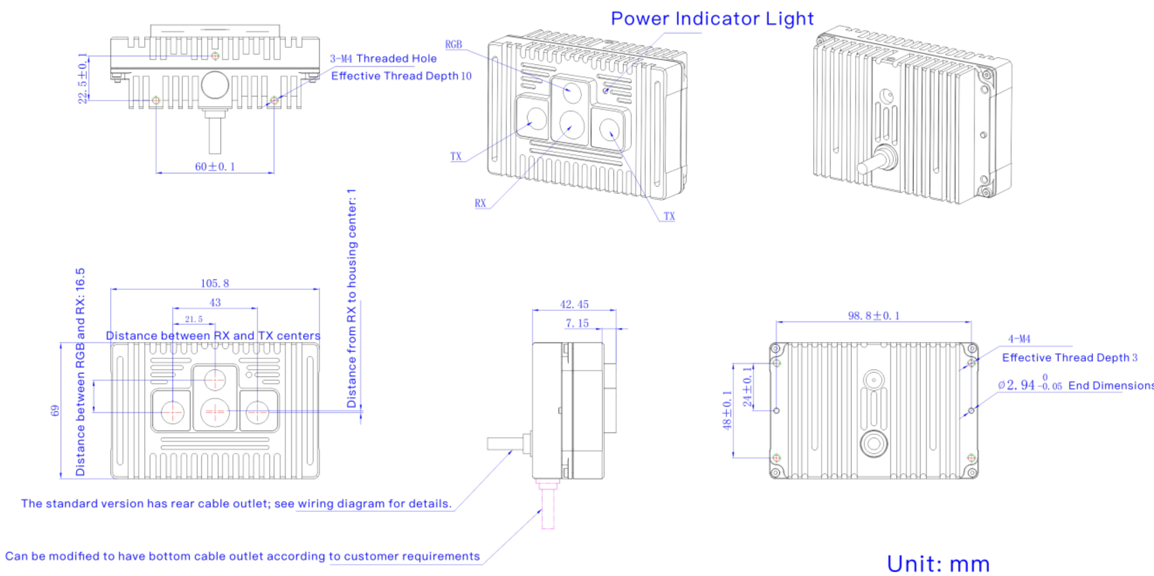

Figure 7 - S10 Ultra Camera Dimensions Diagram

4.1.4 Mechanical File Download

1) 3D Structure File - STEP: pending official release

2) 2D Drawing: download

Important: *Please confirm the latest dimensions and documents with us prior to integration.*

4.2.5 Photo of the physical product

Figure 8 - S10 Ultra Photography

Figure 9 - S10 Ultra MIPI Photography

4.3 S11 Camera

4.3.1 Camera Interfaces

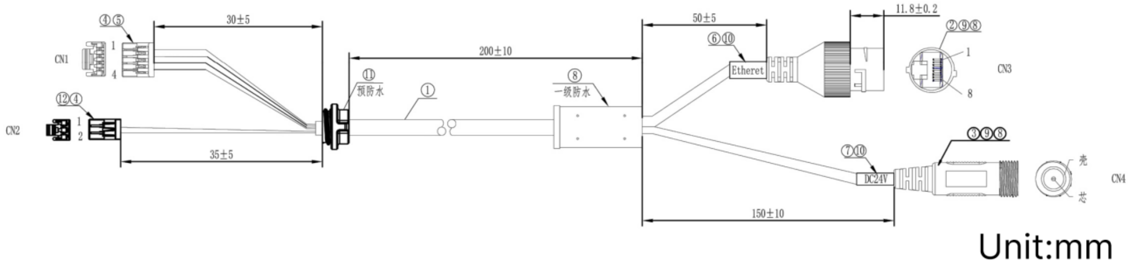

Figure 10 - S11 Camera Interface Diagram

4.3.2 Component Overview

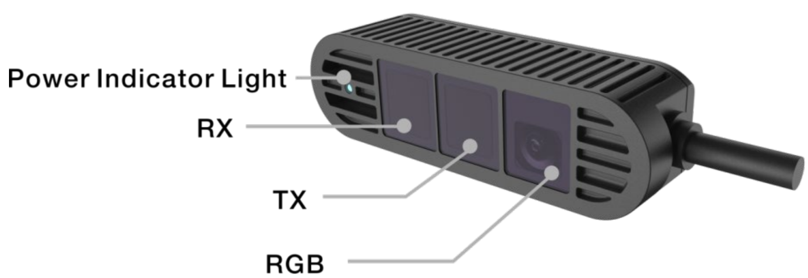

Figure 11 - Overview of S11 Camera (Ethernet Interface)

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4.3.3 Mechanical Dimensions

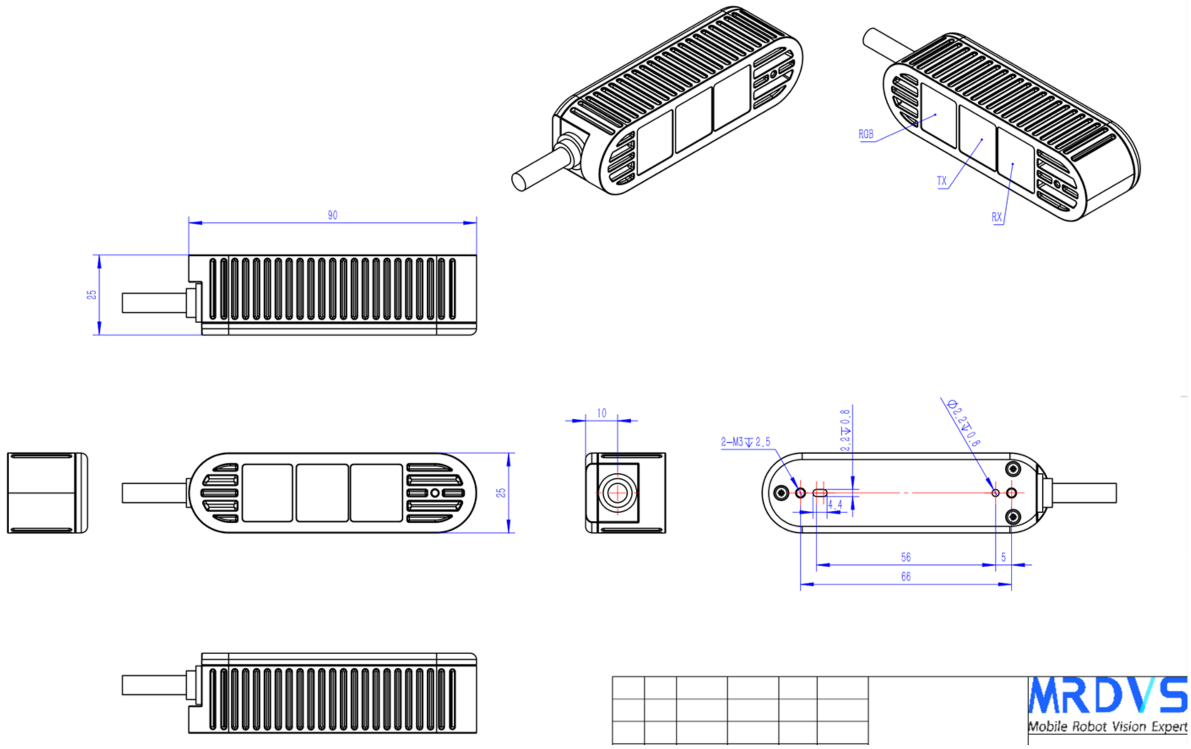


Figure 12 - S11 Camera Dimensions Diagram

4.3.4 Mechanical File Download

1) 3D Structure File - STEP:

Ethernet Interface

USB Interface

2) 2D Drawing:

Ethernet Interface

USB Interface

Important: *Please confirm the latest dimensions and documents with us prior to integration.*

4.3.5 Photo of the physical product

Figure 13 - S11 Photography

4.4 S10 Ultra MIPI Module

4.4.1 Mechanical Dimensions

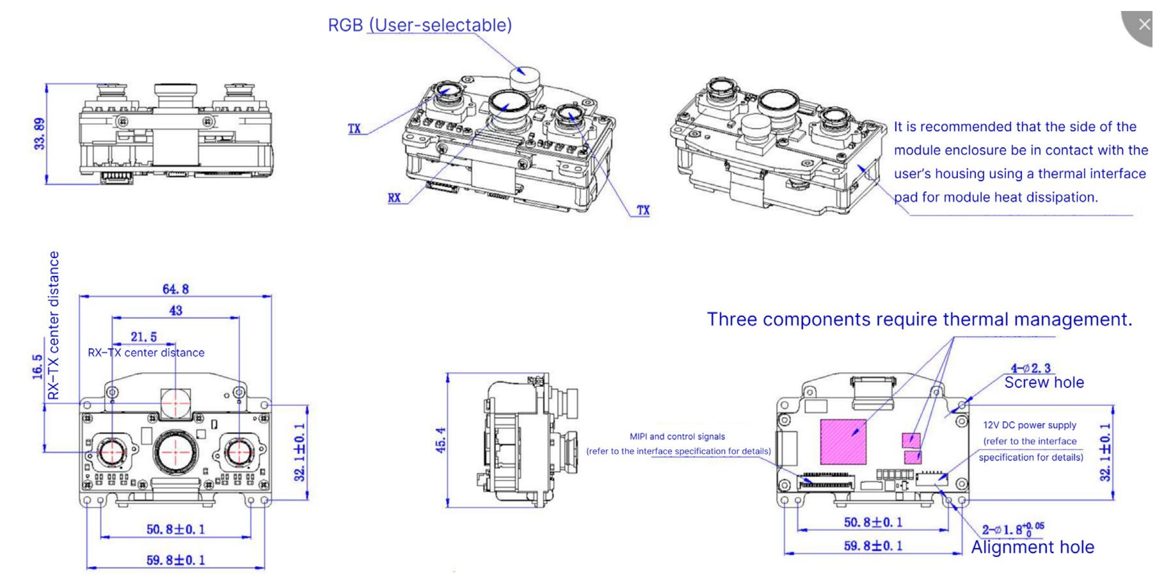


Figure 14 - S10 Ultra Camera Dimensions Diagram

4.4.2 Photo of the physical product

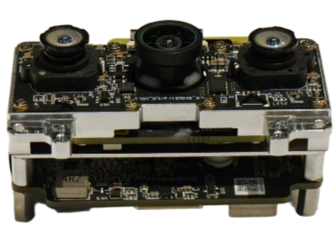


Figure 15 - S10 Ultra MIPI Photography

4.5 S11 MIPI Module

4.5.1 Photo of the physical product

Figure 16 - S11 MIPI Photography

5. Output Data Formats and Visualization

This chapter details the data formats output by the S Series cameras and provides guidance on how to visualize them using common third-party software.

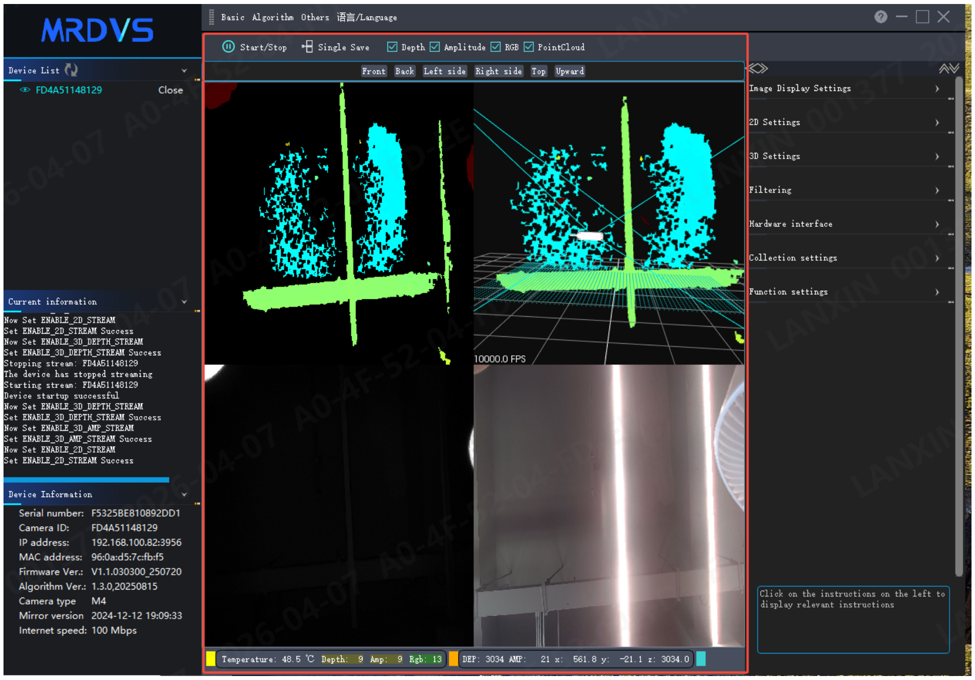
5.1 Software Download and Development Support

Different packages of the SDK (for C/C++, Python, ROS 1, ROS 2) and the GUI viewer binaries (for Windows and Ubuntu), along with their corresponding user manuals, can be downloaded via the MRDVS GitHub channel:

Lanxin-MRDVS/CameraSDK: camera SDK of MRDVS

5.2 GUI Software: LxCameraViewer

LxCameraViewer is the official GUI software for all MRDVS cameras. It supports displaying depth maps, intensity maps, point clouds, and RGB images, and allows users to read and configure basic camera settings as well as algorithm parameters. The software also provides camera temperature monitoring, frame rate display, pixel value readout, and real-time status feedback. Users can view and save image data, camera configurations, detailed algorithm data, and device information such as serial number, firmware version, and IP address.



For detailed instructions, refer to the LxCameraViewer User Manual:

MRDVS-wiki/LxCameraViewer-User-Manual.md at main · Lanxin-MRDVS/MRDVS-wiki

5.3 Data Output Formats and Samples

The S Series cameras can output multiple synchronized data streams shown as below.

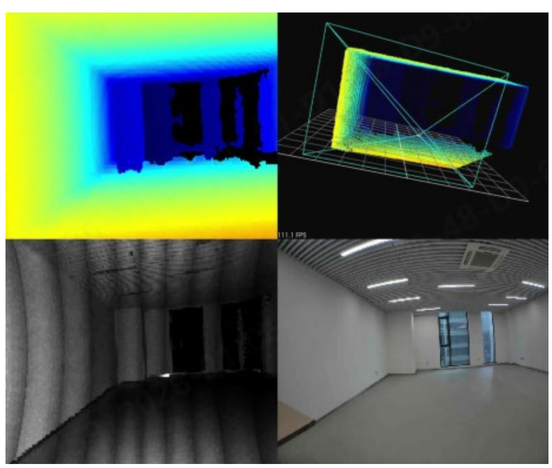


Figure 10 - Example GUI Visualization: Camera Multimodal Data

(Top Left: Depth Map | Bottom Left: Intensity Map | Top Right: Point Cloud Map | Bottom Right: RGB Map)

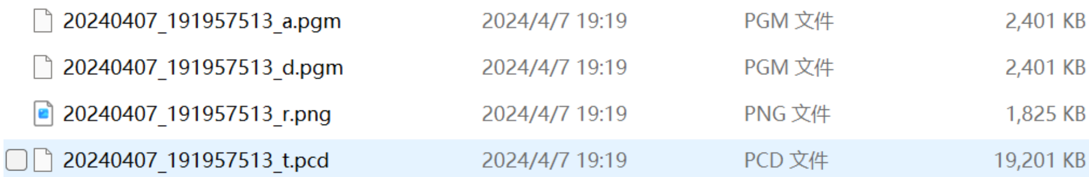


Figure 11 - Example Saved Output Data Files

(From top to bottom: Intensity Map (_a.pgm), Depth Map (_d.pgm) , RGB Image (_r.png), Point Cloud (_t.pcd))

Output Data Type	Description	Format
Depth Map	A pseudocolor image where each pixel's color corresponds to the distance from the camera. Warmer colors (e.g., red/yellow) represent closer objects, cooler colors (e.g., blue/purple) represent farther objects.	.pgm
Intensity (Amplitude) Map	A grayscale image representing the strength of the reflected infrared signal. Higher values indicate stronger reflection. Please note the vertical striping appears due to the dToF SPAD sensor's region-based exposure architecture and parallax. This is an inherent characteristic of dToF technology and does not affect depth accuracy.	.pgm
Point Cloud	A 3D point cloud file (PCD format) containing XYZ coordinates for each pixel, derived from the depth map and camera intrinsics.	.pcd
RGB Image	A standard color image from the onboard RGB camera, spatially aligned with the depth map.	.png

Table 2 Output Data Type and Description

5.4 Recommended Third-Party Software

We recommend the following free, open-source software to inspect the exported data files:

- For Point Cloud (*.pcd files):
  - Recommended Software: CloudCompare
  - Download Link: CloudCompare - Open Source project
  - Usage: Open the .pcd file directly to visualize, rotate, measure, and analyze the 3D point cloud.
- For Depth and Intensity Maps (*.pgm files):
  - Recommended Software: ImageJ
  - Download Link: ImageJ
  - Usage: Open the .pgm file. You can use the analysis tools to check pixel values, profiles, and histograms. Note that depth maps are typically encoded in millimeters.
- For RGB Images (*.png files):
  - These can be opened with any standard image viewer (e.g., Windows Photos, Preview on macOS).

6. Obstacle Avoidance Algorithm

To help users integrate S Series products more quickly, our team has developed the following algorithms tailored to different obstacle avoidance scenarios and application needs. These are offered as two tiers: Obstacle Avoidance 1.0 and Obstacle Avoidance 2.0.

6.1 Ready-in-Use Obstacle Avoidance 1.0 (Embedded)

Obstacle Avoidance 1.0 is embedded directly into different S Series camera models. It relies on the camera's onboard computing power for localized processing, eliminating dependency on external industrial PC resources. This lightweight, real-time design is optimized for robotic operation scenarios.

Principle of Obstacle Detection:

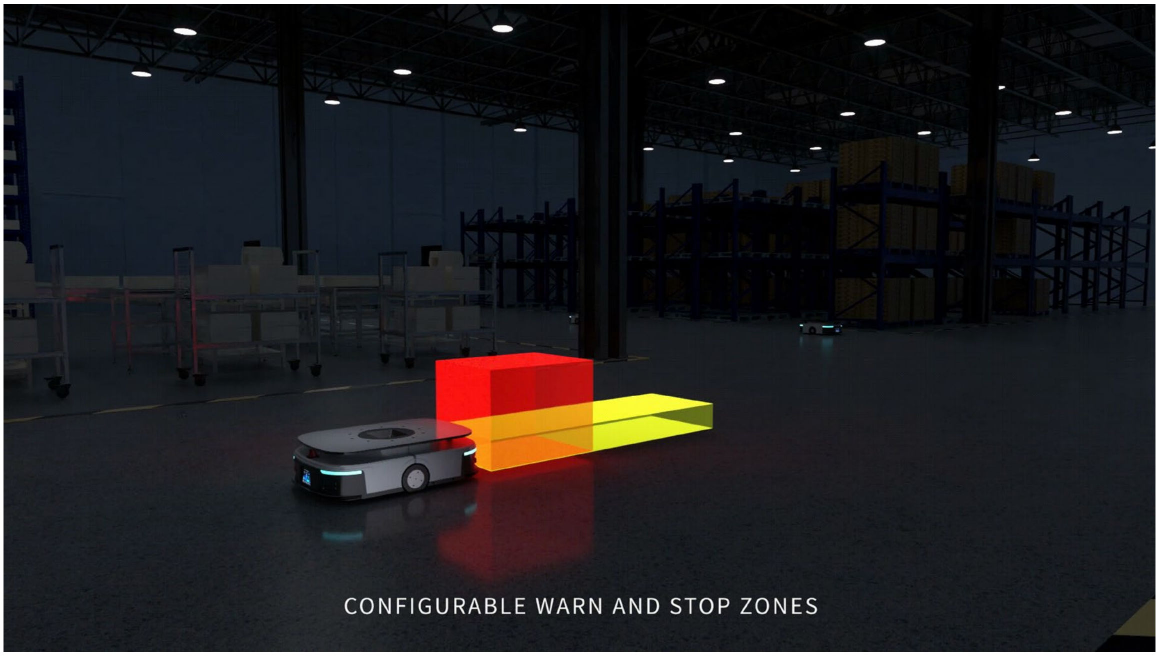
If the number of point cloud points within the predefined detection area exceeds a preset threshold (default: 20 points; adjustable based on actual requirements), the area is determined to contain an obstacle.

Key features include:

1) Point Cloud Coordinate Transformation
Using calibrated camera extrinsic parameters, the original point cloud data collected by the camera is accurately transformed into the robot's coordinate system, eliminating perspective distortion and ensuring obstacle localization accuracy.

2) Zone Intrusion Detection
Supports two customizable obstacle detection zone models: rectangular detection zone and cone-shaped detection zone. These adapt to various robotic operation scenarios including straight travel, turning, and wide-angle detection.

3) Graded Obstacle Avoidance Signal Output
Monitors intruding point clouds within the target zone in real time. Based on the intrusion level, three levels of control signals are output via USB/Ethernet communication protocols, following a unified signal definition. (The S10 also offers a customized model supporting I/O interface.)



6.2 Obstacle Avoidance 2.0 (External Processing)

Obstacle Avoidance 2.0 is fully backward compatible with all features of version 1.0. To address the limitations of traditional point-cloud-based obstacle avoidance (e.g., no clustering, no recognition, weak scenario adaptability), version 2.0 introduces four new core capabilities that significantly enhance robotic obstacle avoidance intelligence and safety.

1) Object Clustering Detection (No Semantic Meaning Required)

Version 1.0 only detects intruding point clouds, without the ability to distinguish scattered versus clustered obstacles. This often leads to false triggers from single points and unclear obstacle contour recognition.

Version 2.0 adds a clustering algorithm that automatically identifies spatially connected point cloud clusters within the target area, performs autonomous clustering, eliminates isolated noise points, and accurately calculates the bounding box of each independent obstacle, outputting obstacle position and size information. This enables robots to not only perceive *that* an obstacle exists, but also understand *where* it is and *how large* it is.

2) Ground Void / Depression Detection (DEMO Version)

Version 1.0 only supports detection of protruding obstacles and cannot recognize hazardous scenarios such as ground depressions, voids, or step gaps, posing safety risks for traversal.

Version 2.0 adds ground void detection capability (DEMO version), which identifies depressions, deep pits, and void areas on the operating surface through point cloud elevation difference features. When a hazardous void intrudes into the detection zone, it automatically triggers an emergency stop, addressing a critical gap in traditional obstacle avoidance systems and adapting to outdoor and complex terrain operations.

3) Customizable Semantic Obstacle Avoidance

Version 2.0 introduces neural-network-based AI semantic recognition capability, supporting custom model deployment. Depending on specific operational requirements, users can train and load targeted recognition models to accurately distinguish different obstacle types such as pedestrians, vehicles, equipment, walls, and debris enabling targeted obstacle avoidance. It also outputs precise bounding boxes of semantic obstacles, supporting advanced strategies like graded avoidance and path planning for rerouting. Unlike version 1.0's undifferentiated physical point cloud avoidance, version 2.0 delivers a significant leap in intelligence.

4) Dynamic Parameter Configuration

There is a difference in debugging flexibility between the two versions:

- Version 1.0: Supports only wired debugging via an external host computer. All obstacle avoidance parameters (detection zone size, trigger threshold, signal sensitivity, etc.) must be modified through a connected host computer, with no real-time dynamic adjustment capability. This results in low scenario adaptation efficiency.
- Version 2.0: Adds dynamic configuration capability, supporting real-time, online modification of various obstacle avoidance parameters without the need for a host computer. Detection thresholds, zone ranges, and response

logic can be dynamically adjusted based on site conditions, robot speed, and scenario requirements. This enables rapid adaptation to diverse scenarios, greatly improving debugging convenience and field adaptability.

7. Product SLAM Algorithm (LiDAR-Vision-IMU Fusion)

To help users quickly deploy SLAM on the MRDVS S10 Ultra sensor, we provide an adapted integration of open-source LIO (LiDAR-Inertial Odometry) and LIVO (LiDAR-Visual-Inertial Odometry) algorithms. Our work is based on the following excellent open-source repositories:

- FAST-LIO (https://github.com/hku-mars/FAST_LIO)
- FAST-LIVO2 (https://github.com/hku-mars/FAST-LIVO2)
- rpg_vikit (https://github.com/xuankuzcr/rpg_vikit.git)

All adaptation code, configuration files, and integration guides are publicly available in our GitHub repository:

https://github.com/Lanxin-MRDVS/MRDVS-S10Ultra_Mapping

The repository provides:

- Ready-to-use launch files (mapping_s10u.launch, mapping_fast_livo2.launch)
- Parameter configuration templates (s10u.yaml, camera_pinhole_s10u.yaml)
- Intrinsic and extrinsic calibration guides
- Notes on LiDAR exposure timing and point cloud timestamp handling

For detailed compilation, configuration, and execution instructions, please refer to the README in the repository.

8. More Application Algorithms Overview (MRDVS & Partner Ecosystem)

Based on the core capabilities of the S Series depth cameras, MRDVS and our certified partners have developed a rich portfolio of application algorithms covering logistics, industrial automation, commercial intelligence, and agricultural robotics.

These algorithms are designed to work seamlessly with S Series cameras and can be directly integrated into customer applications.

8.1 MRDVS Proprietary Algorithms (Logistics & Industrial Automation)

- Warehouse Pallet Slot Occupancy Detection - Real-time detection of pallet slot status (occupied/empty), suitable for AGV docking guidance.
- Multi-Camera Volumetric Measurement (2-4 camera stitching) - Supports dimensioning of regular and irregular parcels using 2–4 stitched cameras, designed for dimensioning systems.
- Pallet Recognition - Accurately identifies pallet pocket locations and centroids to assist forklift AGVs in autonomous docking and pickup. *This capability is enabled by MRDVS's self-developed M-Series iToF Camera with VGA depth resolution.*
- Vision-Guided Depalletizing for Soft Packages, Cartons, etc. (based on MRDVS self-developed M-Series iToF Camera with VGA depth resolution) - Detects and localizes stacked objects such as soft packages and cartons on a pallet layer, outputs grasp points and pose information, and guides robotic arms or depalletizing equipment for automated depalletizing. *This capability is enabled by MRDVS's self-developed M-Series iToF Camera with VGA depth resolution.*

8.2 Partner Algorithms (Commercial Intelligence, HRI & Agricultural Robotics)

MRDVS works closely with multiple industry solution providers to offer additional scenario-specific algorithmic capabilities (available for direct integration or secondary development):

- Turnstile person detection
- Passenger flow counting
- Human pose recognition

- Fruit Recognition & Localization for Robotic Harvesting (e.g., Apples). *This capability is enabled by MRDVS's self-developed M-Series iToF Camera with VGA depth resolution.*

9. Environment and Reliability

Item		S10	S10 Ultra	S11
Operating Environment	Operating Temperature	-20℃ to 60℃	-20℃ to 75℃	-20℃ to 60℃
	Humidity	Max 90%RH	Max 90%RH	Max 90%RH
	Illuminance	0 ~ 100KLUX	0 ~ 100KLUX	0 ~ 100KLUX
Storage Environment	Temperature	-40℃ to 85℃	-40℃ to 85℃	-40℃ to 70℃
	Humidity	Max 90%RH	Max 90%RH	Max 90%RH

Table 3 Product Integration Guide

10. Certification Statement

Note: The certifications listed in this chapter have been completed for the S10. For the S10 Ultra and S11, these certificates have not yet been obtained and are planned to be acquired in Q3 2026.

10.1 Laser Security Level

Laser Safety Guidelines

This product emits invisible laser radiation during operation. Avoid exposure to the eyes to prevent injury.

The laser emitted by this product complies with Class 1 safety requirements. According to EN 60825, it poses no hazard to humans during normal use.

CLASS 1 LASER PRODUCT

This product is classified as a Class 1 laser product under IEC 60825-1:2014. It is safe for normal use under reasonably foreseeable conditions and does not pose a hazard to the eyes.

10.2 European Directives

CE

This product complies with EU CE conformity assessment requirements and meets the specifications of harmonized standards EN IEC 61000-6-2:2019 and EN IEC 61000-6-4:2019.

10.3 European Union RoHS Statement

This product meets RoHS Directive (2011/65/EU Annex II & amendment (EU) 2015/863) requirements. Restricted substances (Cadmium, Lead, etc., including phthalates) passed testing per applicable RoHS standards.

10.4 European Union Regulation

This product complies with the requirements of Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH).

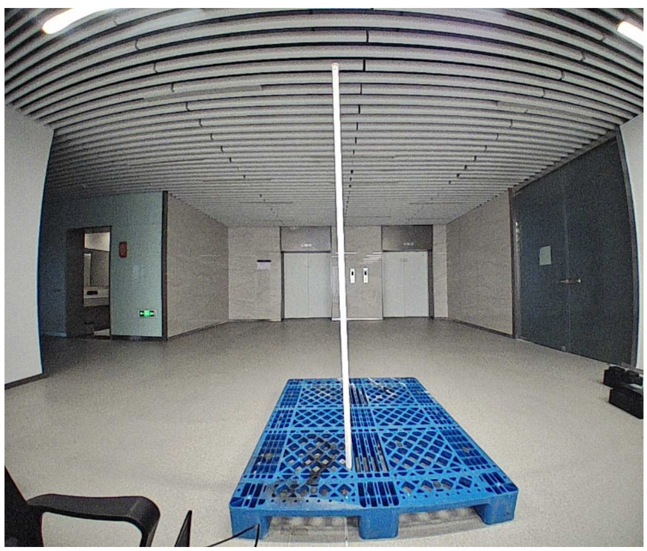
Appendix A: Test Data & Reference Downloads

Ongoing Updates: This section is under active development. While the current reference data is not yet fully comprehensive, we are continuously expanding it with additional test results and reference materials across various application scenarios.

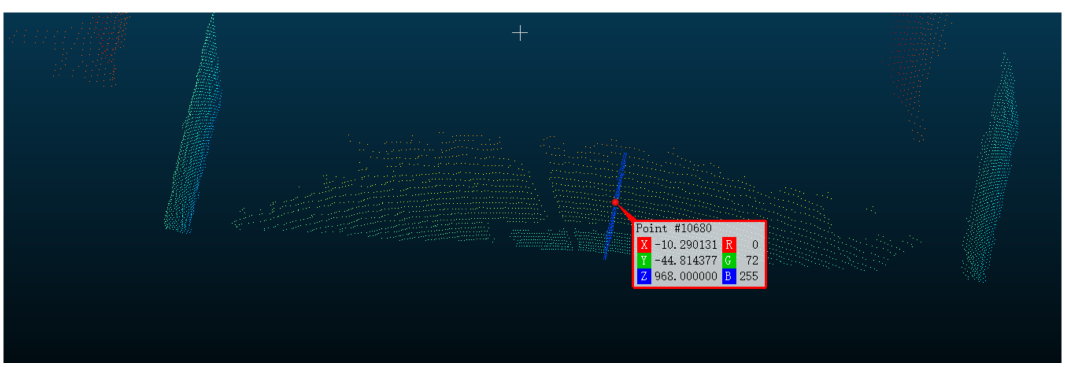
1. Indoor Test - White Rod (Non-Reflective, Ø2cm) at 1m / 2m / 3m

Test Conditions:

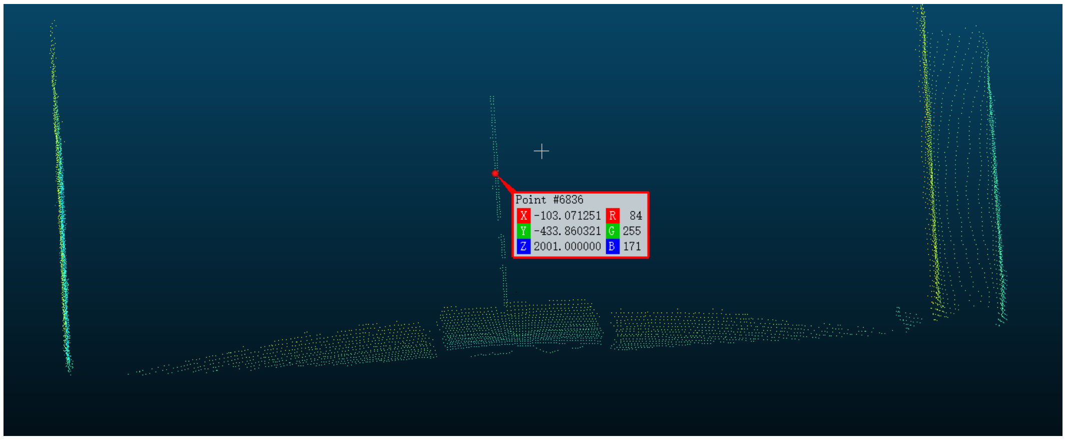
- Environment: Indoor office lighting (approx. 500 Lux)
- Target: White non-reflective rod (diameter: 2cm / Ø2cm)
- Sensor: MRDVS S11 (dToF RGB-D camera)
- Ambient temperature: 25°C



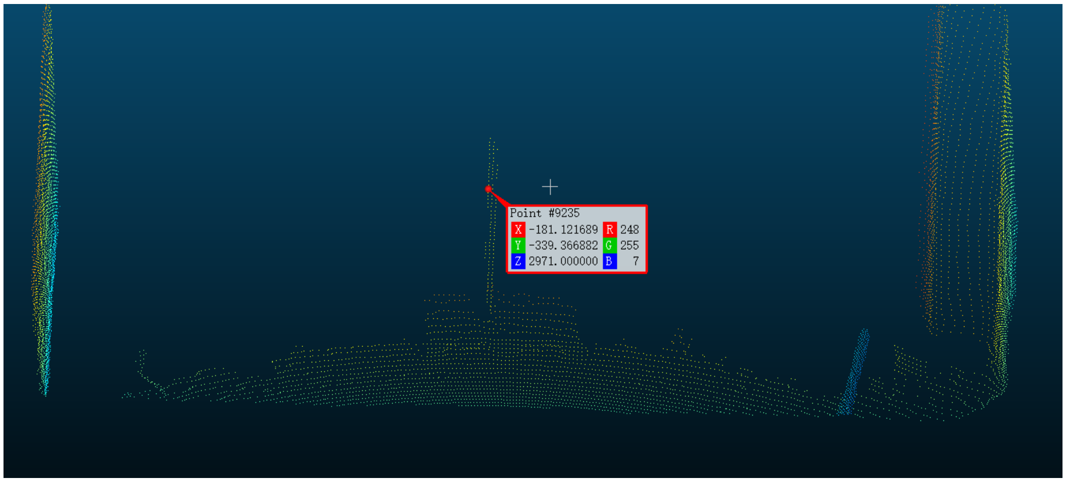
1m data:



2m data:



3m data:



Complete test raw data can be downloaded [here](#).

Observation:

Within 3 meters indoors, the 2cm-diameter white rod is clearly detected with stable distance readings. However, the point cloud is not completely straight beyond 2 meters, intermittent gaps and irregularities appear along the rod due to incomplete pixel data.

Appendix B: Distance vs. Resolution Calculation Guide

1. Field of View (FoV) & Resolution Specifications

Parameter	S10	S10 Ultra	S11
Depth Resolution	240 × 160	240 × 160	240 × 96
TOF FOV (H × V)	120° × 80°	120° × 80°	140° × 56°

2. Calculation Formulas

At a given distance D (in meters) from the camera to the target plane:

Horizontal Coverage:

$$\text{H Coverage} = 2 \times D \times \tan\left(H/2\right)$$

Vertical Coverage:

$$\text{V Coverage} = 2 \times D \times \tan\left(V/2\right)$$

Pixel Spacing (distance between two adjacent pixels):

$$\text{H Pixel Spacing} = \text{H Coverage}/\text{H Resolution}$$

$$\text{V Pixel Spacing} = \text{V Coverage}/\text{V Resolution}$$

3. Simplified Calculations by Model

3.1 For S10 & S10 Ultra (120° × 80°, 240 × 160)

Parameter	Formula	Simplified
Horizontal Coverage	$2D \times \tan(60°)$	$3.464 \times D$

Parameter	Formula	Simplified
Vertical Coverage	$2D \times \tan(40°)$	$1.678 \times D$
Horizontal Pixel Spacing	$(3.464 \times D)/240$	$0.01443 \times D$
Vertical Pixel Spacing	$(1.678 \times D)/160$	$0.01049 \times D$

3.2 For S11 (140° × 56°, 240 × 96)

Parameter	Formula	Simplified
Horizontal Coverage	$2D \times \tan(70°)$	$5.494 \times D$
Vertical Coverage	$2D \times \tan(28°)$	$1.064 \times D$
Horizontal Pixel Spacing	$(5.494 \times D)/240$	$0.02289 \times D$
Vertical Pixel Spacing	$(1.064 \times D)/96$	$0.01108 \times D$

4. Reference Table: Coverage Area & Pixel Spacing

For S10 Ultra (120° × 80°, 240 × 160)

Distance (D)	Horizontal Coverage	Vertical Coverage	H Pixel Spacing	V Pixel Spacing
0.5 m	1.73 m	0.84 m	0.72 cm	0.52 cm
1 m	3.46 m	1.68 m	1.44 cm	1.05 cm
2 m	6.93 m	3.36 m	2.89 cm	2.10 cm
5 m	17.32 m	8.39 m	7.22 cm	5.24 cm
10 m	34.64 m	16.78 m	14.4 cm	10.5 cm
20 m	69.28 m	33.56 m	28.9 cm	21.0 cm
30 m	103.92 m	50.34 m	43.3 cm	31.5 cm
35 m	121.24 m	58.73 m	50.5 cm	36.7 cm

For S11 (140° × 56°, 240 × 96)

Distance (D)	Horizontal Coverage	Vertical Coverage	H Pixel Spacing	V Pixel Spacing
0.5 m	2.75 m	0.53 m	1.14 cm	0.55 cm
1 m	5.49 m	1.06 m	2.29 cm	1.11 cm

Distance (D)	Horizontal Coverage	Vertical Coverage	H Pixel Spacing	V Pixel Spacing
2 m	10.99 m	2.13 m	4.58 cm	2.22 cm
5 m	27.47 m	5.32 m	11.4 cm	5.54 cm

5. Example Usage

Example 1: Short-range Application (S10 at 1~2 meters)

Scenario: AGV obstacle detection at 1.5 meters using S10.

At D = 1.5 m:

- Horizontal Coverage = 3.464 × 1.5 = 5.20 m
- Vertical Coverage = 1.678 × 1.5 = 2.52 m
- H Pixel Spacing = 1.44 cm × 1.5 = 2.16 cm
- V Pixel Spacing = 1.05 cm × 1.5 = 1.58 cm

Interpretation: At 1.5 meters, each pixel covers approximately 2.2 cm × 1.6 cm. This is sufficient to detect small obstacles (e.g., a 5 cm × 5 cm object will occupy ~2-3 pixels), making the S10 well-suited for close-range AGV obstacle detection.

Example 2: Long-range Application (S10 Ultra at 10~35 meters)

Scenario: Safety perimeter monitoring or long-range obstacle detection at 30 meters using S10 Ultra.

At D = 30 m:

- Horizontal Coverage = 3.464 × 30 = 103.92 m
- Vertical Coverage = 1.678 × 30 = 50.34 m

- H Pixel Spacing = 14.4 cm × 3 = 43.3 cm
- V Pixel Spacing = 10.5 cm × 3 = 31.5 cm

Interpretation: At 30 meters, each pixel covers approximately 43 cm × 31 cm. Assuming the camera is facing a standing person from the front or back (not top-down), a typical adult standing person (approx. 50 cm wide × 170 cm tall) occupies only ~1 pixel horizontally × ~5 pixels vertically in the depth image.

Smaller objects, or a human in certain postures (e.g., crouching), will occupy even fewer pixels. This makes reliable detection and posture recognition challenging at this range.

- ✅ Distance measurement - works beyond 30m for large surfaces
- ❌ Small object detection - becomes unreliable beyond 30m due to insufficient resolution

This is not a limitation of dToF technology itself, but a physical constraint of pixel count over distance.

Appendix C: Installation Guidance

Proper installation is critical to ensure optimal sensor performance.

FOV Clearance

Ensure no structural components (housing edges, ribs, brackets) intrude into the sensor's nominal FOV; mount the sensor centered within the opening. *Otherwise, FOV truncation may cause fixed blind areas, false close-range readings, and obstacle avoidance failures.*

Particularly during initial testing, it is recommended to place the sensor on a support 20~30 cm above the ground with no obstructions in its field of view, as the image shown above.

Optical Path

Keep the sensor at least 10 cm away from highly reflective surfaces (polished metal, mirrors, glossy plastics). *Otherwise, near-field IR crosstalk or multi-path interference may cause distance distortion, data corruption, or receiver saturation.*

Mechanical Mounting

Apply moderate and even torque; avoid over-tightening. Use soft gaskets or spacers if needed. *Otherwise, mounting stress may cause lens deformation or optical axis shift, resulting in distance offset.*

Thermal Management

Provide adequate ventilation, especially in enclosed spaces; avoid heat sources. *Otherwise, temperature rise may cause distance drift and long-term performance degradation.*

Window Maintenance

Implement a regular cleaning schedule for dusty or humid environments. *Otherwise, contamination or fogging will degrade signal-to-noise ratio.*

Appendix D: Quick Start & Diagnostic Guide

1. Power Connection

Connect the camera to an appropriate power source according to its interface type: for models with a DC input, use a DC power supply within the specified voltage range (e.g., 12–24V DC, 3A); for models supporting 5V USB power, ensure the source provides stable 5V power with sufficient current (e.g., 5V, 2A). Once properly connected, the blue power indicator will flash slowly, indicating normal power-on. Please refer to the product specifications for the exact voltage, current, and interface requirements of your specific model.

2. Network Connection

Connect the camera to the computer via the required cable (Ethernet or USB).

3. Computer Network Configuration

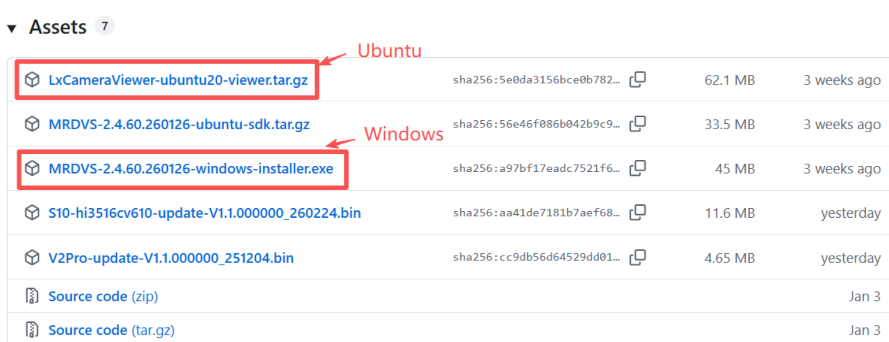
Set your computer's IP address to the same subnet as the camera (default camera IP: 192.168.100.82) and disable the computer's firewall.

4. Install GUI Tool

Note: The GUI is required for device status checking, firmware update, image testing, parameter setting, IP changing, etc.

Download the GUI Tool:

https://github.com/Lanxin-MRDVS/CameraSDK/releases



Note:

- The Windows version is recommended as it offers greater stability.

- It is recommended to install the software to a non-system drive (e.g., D: drive) or to run the program as an administrator, as installing to the default C: drive may cause permission issues.

5. Check and Update the Embedded Firmware to the Latest

5.1 Check Current Firmware Version

Launch the installed `LxCameraViewer.exe` software, locate your device in the Device List, and check the Device Information to see the current firmware version.

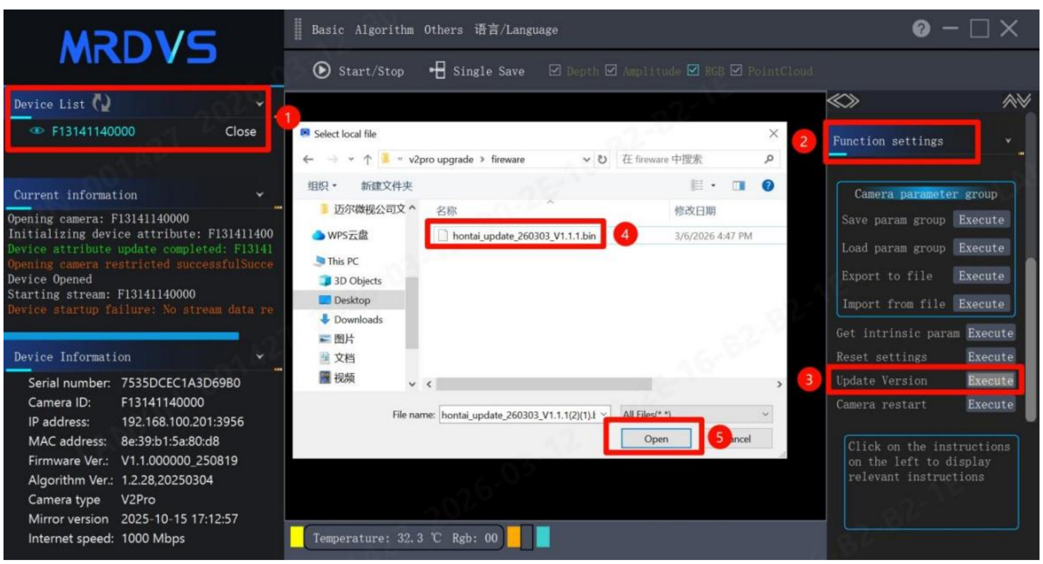
Compare it with the latest firmware version shown in the GitHub Release. If the current firmware version does NOT match the latest version in GitHub Release, an update is required. Please follow steps 5.2 and 5.3 below.

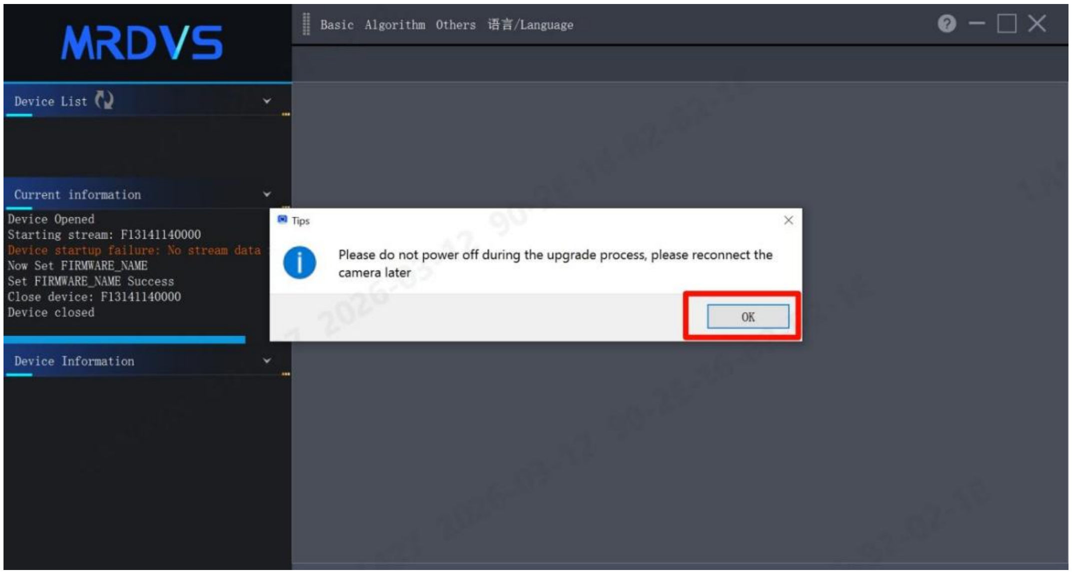
5.2 Download the latest Firmware

https://github.com/Lanxin-MRDVS/CameraSDK/releases

Firmware Name: S10-xxxxupdate_Vxxx_xxxxxx.bin

5.3 Follow the instructions shown below to upgrade the firmware;

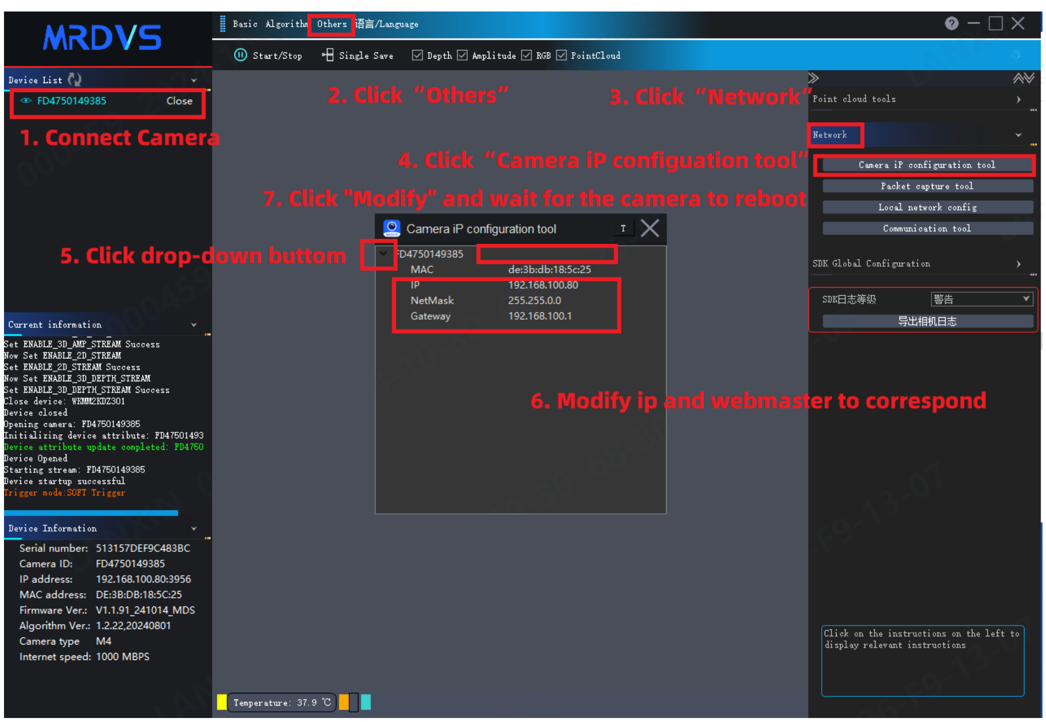




The upgrade process takes approximately one minute. Once complete, reopen the device in the Device List and check Device Information to verify the firmware version has been successfully updated.

5.4 Modify Device IP Address (if needed)

If the target device requires a different IP address, it can also be modified using the GUI tool (see screenshot below).

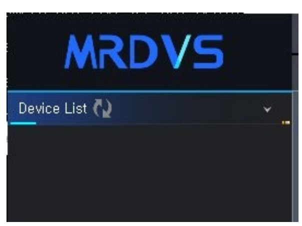


6. Installation and FOV Clearance

After completing the software and firmware setup, ensure proper physical installation of the camera. Particularly during initial testing, it is recommended to place the sensor on a support 20~30 cm above the ground with no obstructions in its field of view, as shown in the image below.

7. Diagnostic Guide

7.1 Camera Not Detected by the GUI Viewer



If the GUI viewer cannot find the camera, follow the diagnostic steps below:

- LED Status - Observe the camera's LED indicator. Confirm whether it is blinking blue (normal operation) or solid blue (may indicate a communication issue).

- Power Supply - Verify that the power supply provides the correct voltage and the current.
- Network Cable & NIC - Check whether the network interface card (NIC) connection shows a "X" or "disconnected" icon. If so, inspect the Ethernet cable and the computer's NIC for proper function.
- IP Configuration & Packet Capture - If the above steps do not resolve the issue, verify the camera's IP address. Use Wireshark or a similar packet capture tool to check for network packets from the camera.

  Note: The camera currently has no hardware reset button or function to display its modified IP address. If the IP address has been changed and is no longer known, recovering it can be challenging. In such cases, the packet capture method described above is the most effective way to identify the current IP.
- Log File Analysis (Alternative Method to Retrieve IP Address) - If packet capture is not feasible or you are unsure how to perform it, you may retrieve the camera's IP address by sending the log file to MRDVS for analysis.

  Prerequisite: This method only works if the camera has been successfully opened on any computer before. If this condition is met, locate the lx_camera.log file (inside the tool/log folder) and send it to MRDVS for IP address retrieval.

7.2 No Data After Opening the Camera

If no data appears after opening the camera with the host computer software, follow the diagnostic steps below

- Firewall - Ensure the firewall is turned off or that the camera software is permitted to pass through.
- IP Configuration - Set the camera and host computer to the same network segment.

- Multiple IP Addresses - If the host computer has obtained multiple IP addresses and the camera has detected the same IP within the local network, select the desired IP address to activate it.
- Network Hardware - Check whether the network switch or cables are malfunctioning.
- Computer - Try replacing the host computer to isolate the issue.
- Network Segments - Configure multiple network segments if required by the environment.
- GUI Version - If the GUI cannot display images or the image is abnormal, refresh the GUI viewer to the latest version.
- Application Permissions - If the error "failed to exclusively acquire application permissions" appears, ensure that only one user is connected to the camera at the same time.

7.3 Image Quality Issues

Issue	Recommended Action
Edges of nearby white objects are less precise	The glare algorithm has been optimized, but detection of black objects may still be incomplete.
Reflective pillar location is overexposed	Turn on the glare suppression algorithm.
Imaging of detected object is sparse or missing	Check high exposure parameters (typically 600–1200). Check low signal threshold (typically 10–30).

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Mobile Robot Vision Expert

Appendix E: S10 Ultra MIPI Module Hardware Interface & Technical FAQ

1. Pin Definition

No.	Signal Name	Signal Direction	Signal Type	Signal Level	Description
1	MOD_PWR_EN	Input	LVCMOS	1.8v	Power Enable: 1: Enable module power (amplitude ≥ 1.8V). 0: Disable module power
2	RSV	-	LVCMOS	-	Reserved: Suspended
3	RSV	-	LVCMOS	-	Reserved: Suspended
4	MOD_SYNC_IN	Input	LVCMOS	1.8v	Graphic frame synchronization model: PWM, duty cycle 30% - 70%
5	RSV	-	LVCMOS	-	Reserved: Suspended
6	RSV	-	LVCMOS	-	Reserved: Suspended
7	MOD_SYNC_OUT	Output	LVCMOS	1.8v	Reserved: Suspended
8	GND	-	GND	-	Power ground
9	FPGA_GPIO_1	Input/Output	LVCMOS	1.8v	GPIO: Reserved
10	FPGA_GPIO_2	Input/Output	LVCMOS	1.8v	GPIO: Reserved
11	FPGA_GPIO_3	Input/Output	LVCMOS	1.8v	GPIO: Reserved
12	FPGA_GPIO_4	Input/Output	LVCMOS	1.8v	GPIO: Reserved
13	GND	-	GND	-	Power ground
14	MIPI_CSI_CK_N	Output	Differential clock pair	MIPI D-PHY	MIPI clock signal
15	MIPI_CSI_CK_P	Output	Differential clock pair	MIPI D-PHY	

16	GND	-	GND	-	Power ground
17	MIPI_CSI_D0_N	Output	Differential data pair	MIPI D-PHY	MIPI data signal D0
18	MIPI_CSI_D0_P	Output	Differential data pair	MIPI D-PHY	
19	GND	-	GND	-	Power ground
20	MIPI_CSI_D1_N	Output	Differential data pair	MIPI D-PHY	MIPI data signal D1
21	MIPI_CSI_D1_P	Output	Differential data pair	MIPI D-PHY	
22	GND	-	GND	-	Power ground
23	MIPI_CSI_D2_N	Output	Differential data pair	MIPI D-PHY	MIPI data signal D2
24	MIPI_CS_D2_P	Output	Differential data pair	MIPI D-PHY	
25	GND	-	GND	-	Power ground
26	MIPI_CSI_D3_N	Output	Differential data pair	MIPI D-PHY	MIPI data signal D3
27	MIPI_CSI_D3_P	Output	Differential data pair	MIPI D-PHY	
28	GND	-	GND	-	Power ground
29	REV_I2C_SCL	Input	LVCMOS	1.8v	I2C clock: Supports 100K to 400KHz, 1.8V level
30	REV_I2C_SDA	Bidirection	LVCMOS	1.8v	I2C data: 1.8V level

2. Technical Notes

2.1 Trigger & Synchronization

The device supports the following synchronization features:

- Trigger input (Pin 4, MOD_SYNC_IN): The device synchronizes at the rising edge. The high level should be maintained for 1~10 ms to trigger successfully.
- Duty cycle: Changing the duty cycle does not affect triggering. The device supports trigger control across the full 30~70% duty cycle range.
- Maximum triggering frequency: 10 fps
- Sync output (Pin 7, MOD_SYNC_OUT): Outputs a 25 ms high-pulse signal. The module begins exposure a few hundred microseconds after the signal goes high.

2.2 I2C Communication

- Voltage Level: The I2C interface is 1.8V only (as specified in the pin table). If 3.3V level is required, an external level shifter must be added between the device and the host.
- Data Format: I2C communication allows configuration of certain camera functions and reading of camera operational information. The format consists of a 16-bit register address corresponding to 8-bit data.
- Register Manual: A Register Configuration Reference Manual is available, documenting all I2C-configurable registers. Please contact MRDVS technical support to request this manual.

Appendix F: Use Cases

1. Autonomous Mobile Robotics (AMR)

Products: S10 / S11

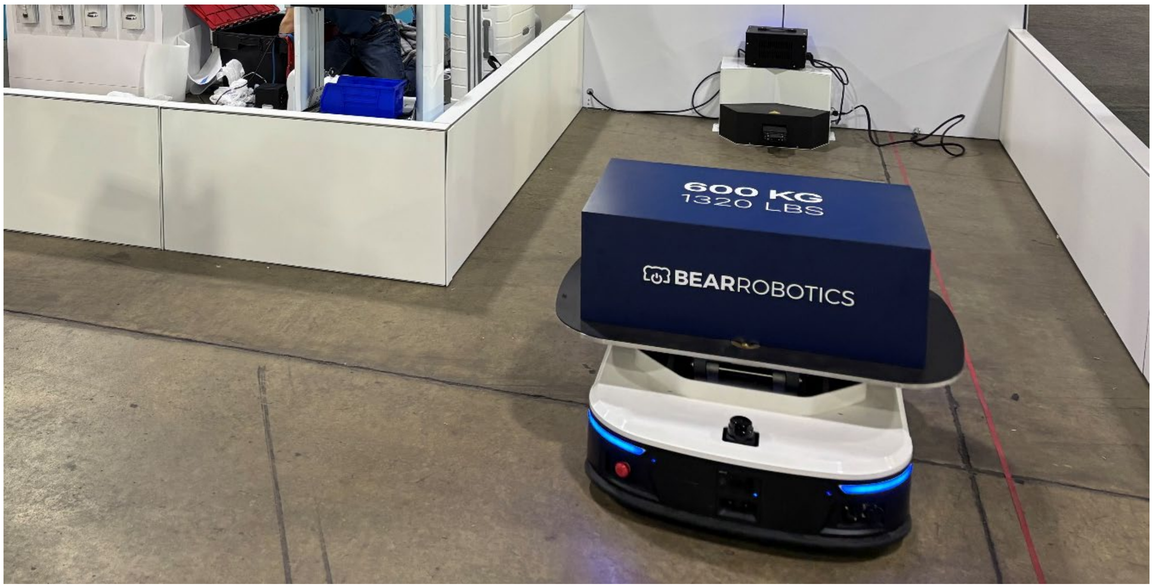
Key advantages leveraged:

- Excellent detection of black and highly reflective obstacles
- Minimal impact from ambient light (indoor/outdoor operation)
- Wide FOV for enhanced scene coverage
- Ethernet interface for reliable industrial communication

Applications:

- Humanoid robot chassis obstacle avoidance
- AGV forklift obstacle avoidance
- AMR (Autonomous Mobile Robot) chassis obstacle avoidance

Status: Shipping in volume to multiple well-known manufacturers and deployed in customer applications.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2. Unmanned Aerial Vehicle (UAV)

Products: S10 Ultra MIPI module

Key advantages leveraged:

- Lightweight and compact MIPI interface for drone integration
- Excellent detection of black and highly reflective obstacles
- Minimal impact from ambient light (outdoor operation)
- Wide FOV for enhanced scene coverage
- Long detection range for aerial applications

Applications:

- UAV SLAM & obstacle avoidance
- Autonomous flight path planning
- Low-altitude terrain following

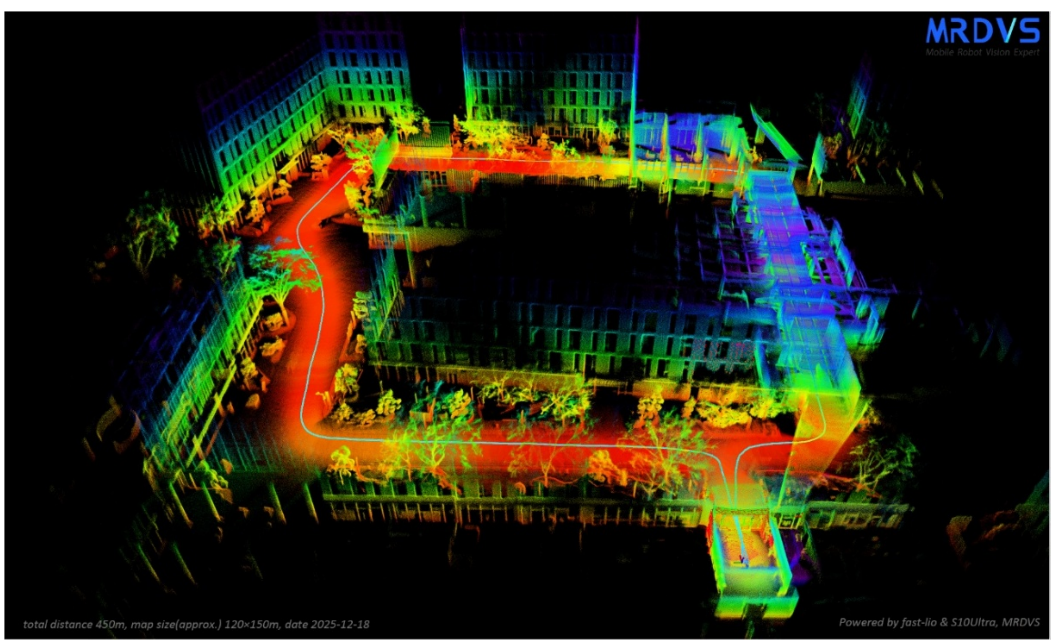
Reference 1 - AI-Powered Power Grid Inspection (DJI-Based Platform)

A leading AI company and pioneer in adaptive drone technologies for power grid inspection has integrated the S10 Ultra into its onboard intelligent terminal developed for DJI drones. The solution delivers multiple grid inspection capabilities including tree obstacle detection along power line corridors, grid construction acceptance for automated quality verification, and adaptive inspection for environment-aware autonomous adjustment.

By processing real-time point cloud output, the system leverages precise spatial features to achieve dynamic environmental adaptation, while high-density point cloud data enables high-precision 3D reconstruction of targets for efficient adaptive inspection and accurate modeling.

Reference 2 - ZJU FAST-Lab (Prof. Fei Gao's Group)

Professor Fei Gao's team at ZJU FAST-Lab has integrated the S10 Ultra MIPI module into their platform for indoor and outdoor LiDAR-Vision fusion SLAM. As a globally recognized leader in aerial robotics, FAST-Lab has developed open-source algorithms including FAST-LIO and FAST-LIVO. The lightweight MIPI interface enables direct integration into compact UAV frames.



Reference 3 - Joint Product Development (Leading UAV Manufacturer)

MRDVS has partnered with a globally recognized UAV manufacturer to enable a complete onboard perception solution. MRDVS provides an integrated hardware platform combining the S10 Ultra MIPI module with an RK3588 computing unit, while the customer develops application-layer software including SLAM, object recognition, and flight control algorithms on top of this platform.

This jointly enabled solution will be co-branded and brought to market as a new product offering in Q4 2026, targeting advanced UAV applications that require tightly integrated onboard perception and computing.

3. Commercial Cleaning Robot

Products: S11 (2-4 units per robot)

Key advantages leveraged:

- Small near-field blind zone for close-range obstacle detection
- Ultra-wide FOV (one S11 replaces two sensors with smaller FOV)
- Minimal impact from ambient light, including direct sunlight and floor-to-ceiling windows
- Consistent full-range accuracy
- Edge following capability for wall and corner cleaning

Status: Volume deliveries have commenced in alignment with two leading global cleaning robot manufacturers' new products launch.

Deployment configuration: 2-4 S11 units per robot, enabling seamless 360° perception for safe and efficient autonomous operation in complex commercial environments (offices, airports, shopping malls, etc.).

Video: https://youtu.be/O4bntYbvruo?si=FvkYaPPak4US6g_f

4. Embodied Quadruped Robot

Products: S11

Key advantages leveraged:

- Ultra-wide FOV for comprehensive surrounding perception
- Stable detection of various obstacle types (black, reflective, textureless)
- Minimal impact from ambient light, enabling reliable indoor/outdoor operation

Applications:

- Quadruped robot obstacle avoidance
- Stair climbing and terrain perception
- Indoor/outdoor exploration

Status: Small-batch deliveries and validation are ongoing with one leading embodied quadruped robot manufacturer.

5. Robotic Lawn Mower

Reference 1 - Sensor Fusion for SLAM + Semantic Obstacle Detection

Products: S10 Ultra / S10 Ultra MIPI

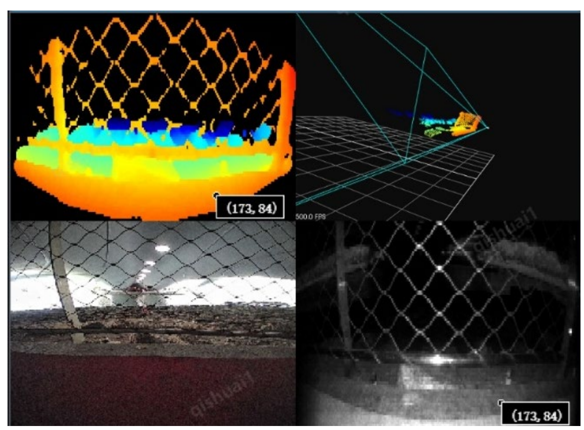
Key advantages leveraged:

- 42m detection range for large-area mapping
- Outdoor ready - stable under direct sunlight
- 80° vertical FOV for better terrain and surrounding perception
- RGB vision fusion - supports FAST-LIVO and semantic recognition
- Built-in IMU (200Hz) for robust SLAM

Applications:

- Outdoor SLAM for ≤ 1,000 ㎡ areas and semantic obstacle recognition
- Terrain perception (slopes, curbs, low obstacles)

Status: Completed joint testing (black-box & white-box) with a major manufacturer; volume shipments have commenced.



Reference 2 - Semantic Obstacle Detection

Products: S11 MIPI

Key advantages leveraged:

- Lightweight MIPI interface for direct integration

- Ultra-wide FoV (140°) for comprehensive coverage
- Outdoor ready - stable under direct sunlight (up to 100kLux)
- Small near-field blind zone for close-range obstacle detection
- Cost-effective solution for price-sensitive consumer applications
- RGB-D data for semantic obstacle recognition (e.g., distinguish between grass, stones, pets, and children)

Status: Joint testing completed with a leading lawn mower manufacturer; Volume production scheduled for Q3 2026.

6. Outdoor Smart Wheelchair / Golf Cart

Products: S10 / S11

Key advantages leveraged:

- Outdoor ready - stable under direct sunlight
- Small near-field blind zone for close-range safety
- Wide FOV for comprehensive scene coverage
- Stable detection of black, reflective, and textureless obstacles

Applications:

- Smart wheelchair obstacle avoidance
- Golf cart collision prevention

Status: Joint testing and validation ongoing with multiple manufacturers with positive results. Small-batch deliveries have commenced with one manufacturer.

7. Outdoor Last-Mile Delivery Robot

Products: S10

Key advantages leveraged:

- Outdoor ready - stable under direct sunlight and varying weather
- Small near-field blind zone for low-speed safety
- Wide FOV for comprehensive scene coverage
- Stable detection of black, reflective, and textureless obstacles

Applications:

- Last-mile delivery robot obstacle detection
- Sidewalk and curb perception

Status: Joint testing and validation ongoing with multiple leading manufacturers with positive results. Small-batch deliveries have commenced with one manufacturer.

8. Passenger Flow Counting & Turnstile Anti-Ticket Evasion Detection

Products: S10 / S11

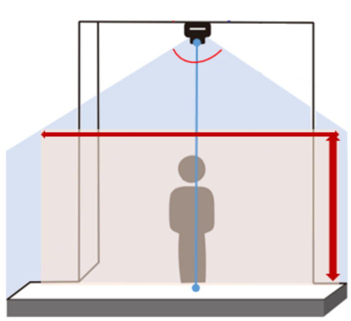
Key advantages leveraged:

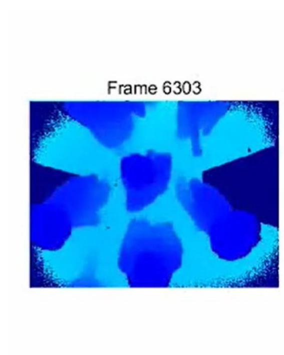
- Wide FOV covers multiple lanes with one sensor
- Minimal impact from ambient light (indoor/outdoor entrances)
- Reliable detection of dark hair
- Small near-field blind zone for close-range detection

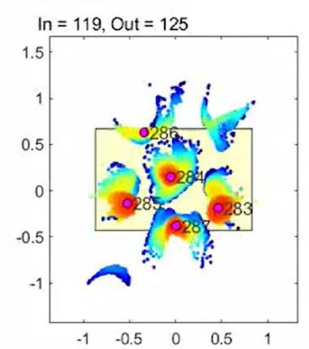
Applications:

- Passenger flow counting
- Turnstile tailgating / anti-ticket evasion detection
- People counting for retail and public facilities

Status: Integrated by multiple customers with customer-developed algorithms. Volume deliveries completed to multiple customers.







9. Large Parcel Volumetric Measurement

Products: S10 (4 cameras, with MRDVS stitching & measurement algorithm)

Key advantages leveraged:

- Fast acquisition & low latency for real-time dimensioning
- Accurate black object detection
- ±3 cm per dimension accuracy
- Wide FOV
- Low multi-camera interference
- High cost-effectiveness

Applications:

- DWS system volume measurement
- Logistics and warehouse dimensioning

Status: Volume shipments and deployments ongoing across system integrators in Spain, South America, India, and other regions.

10. Warehouse Slot Occupancy Detection

The Challenge

In many AGV-equipped warehouses, manual stacking still exists, particularly in dynamic slotting areas (also known as “on-the-fly” slotting zones) or AGV-manual handover stations, preventing the WMS from knowing real-time slot occupancy, which can result in:

- Reduced operational efficiency
- Collisions between AGVs, goods, or equipment
- Potential safety risks to personnel and assets

Limitations of Other Sensors

Single-point LiDAR - Only one laser point per measurement; may miss gaps between cartons or pallets, leading to false occupancy detection.

RGB camera - Deep learning models may fail on objects outside the training set; no height information for stacking tasks.

MRDVS Solution

MRDVS uses the self-developed S series RGB-D camera to provide both 3D geometry and color information, enabling the system to automatically detect presence of goods, placement compliance, and abnormal occupancy. A complete hardware + software solution is provided, along with professional model training and deployment support.

Products: S10 Pro (customized, with on-camera compute power)

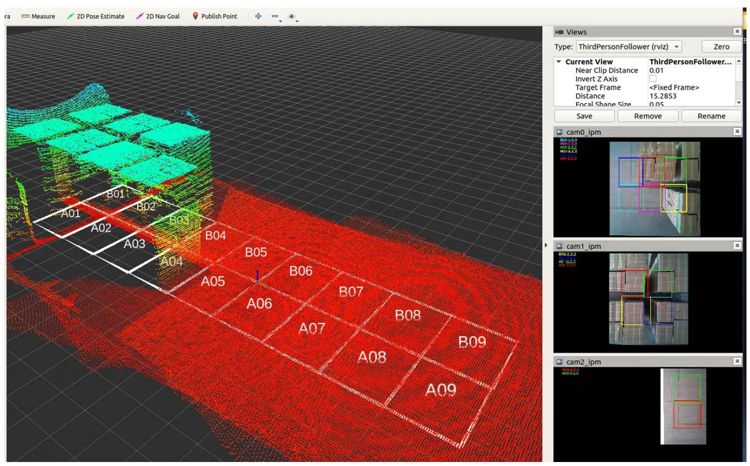
Key advantages leveraged:

- Built-in computing power - no external IPC required
- RGB-D data - 3D geometry + color information for accurate slot detection
- Flexible communication (TCP/IP, UDP, HTTP) with JSON data output

- Easy deployment with on-camera algorithms

Applications:

- Warehouse slot occupancy detection
- Automated inbound/outbound inventory control
- Abnormal occupancy and misplaced load detection
- Pallet presence verification for AGV task dispatch



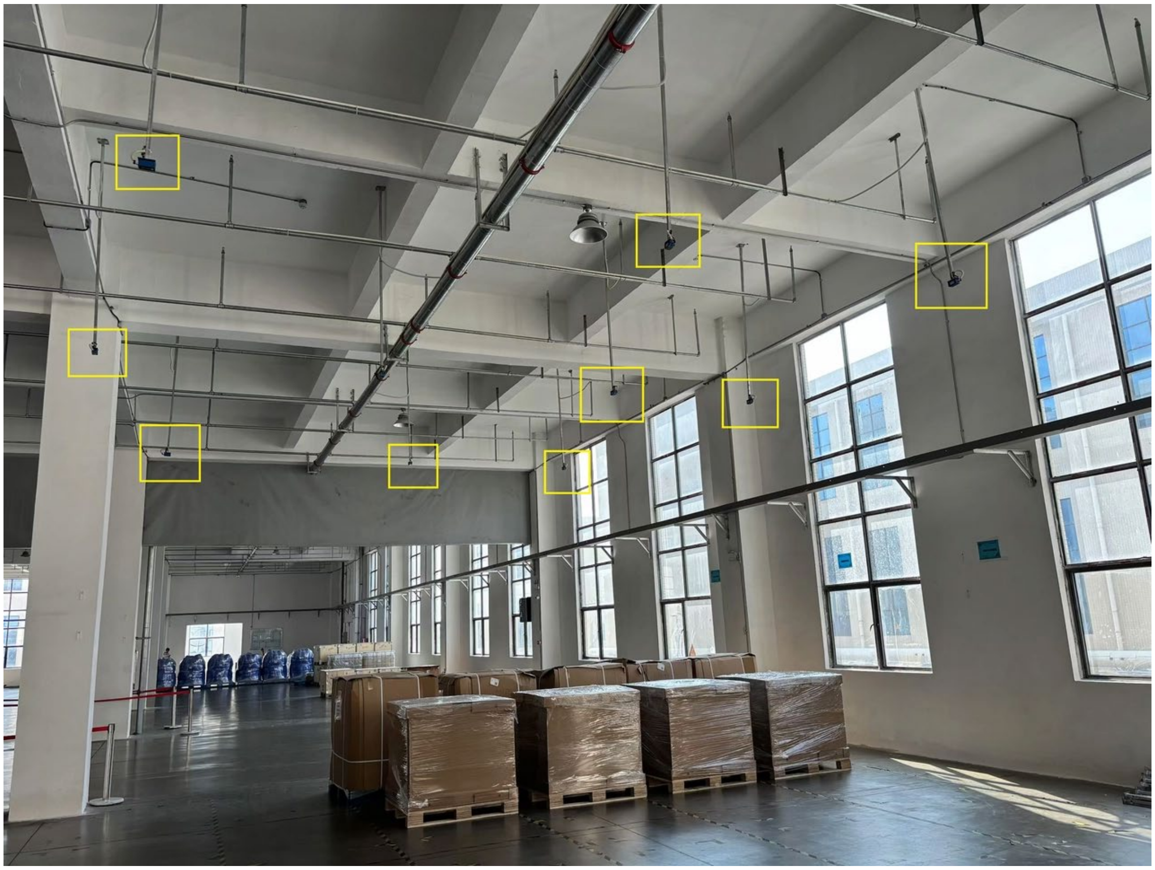
Workflow:

The upper-level control system sends a task request, triggering the camera to capture images and determine the status of the designated warehouse slots. The occupancy result is then reported to the upper system via JSON, enabling intelligent inbound/outbound management.

Communication protocols: TCP, UDP, HTTP

Installation recommendation: Mount the camera on a column or ceiling, directly above the target slot

Status: The solution has been deployed in dozens of warehouse sites, with over several hundred sensors installed.



11. Safety Protection - Personnel & Asset Collision Prevention

Products: S10 / S10 Pro

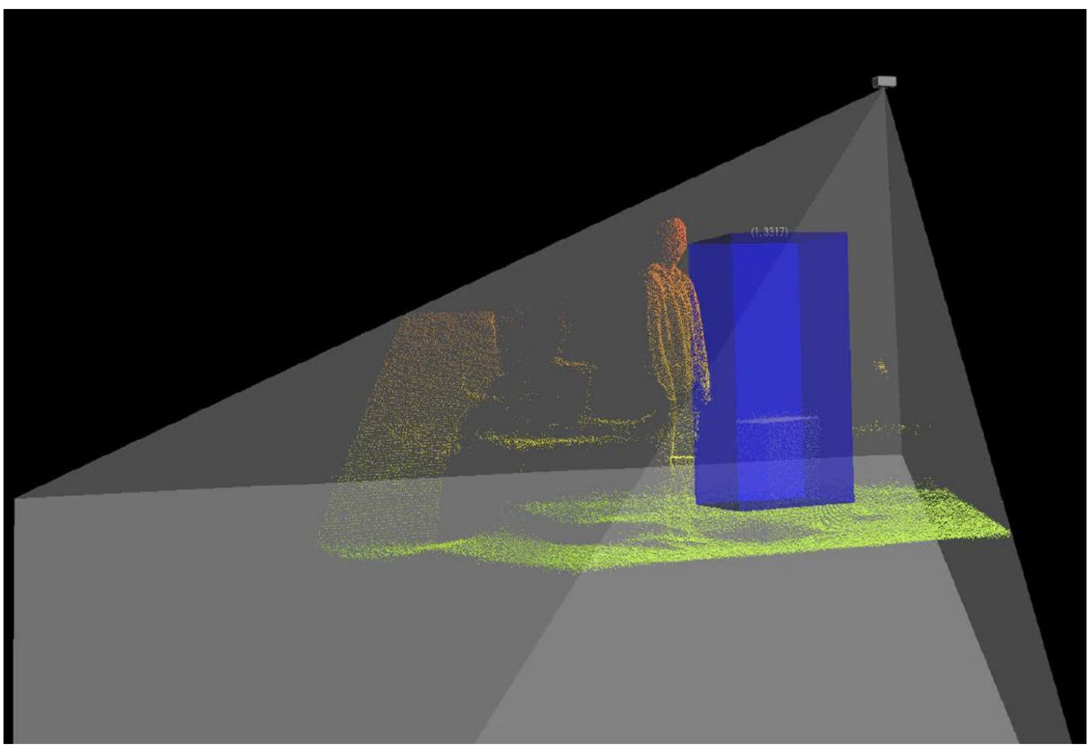
Key advantages leveraged:

- RGB-D data enables AI-powered person-object separation - accurately distinguishes between people and equipment
- Depth-based zone protection - leverages captured depth data for precise warning, buffer, and restricted zone definition with graduated responses

Applications:

- AGV/AMR personnel safety
- Industrial vehicle collision prevention
- Restricted zone enforcement

Status: Currently in joint development and validation with several customers.



Appendix F: Application Notes

F.1 RGB-D Camera Comparison: S11 (dToF) vs. RealSense D435 (Active Stereo)

Update on 29th May. 2026

This document provides a technical comparison between the S11 depth sensor and the Intel RealSense D435. The analysis covers key aspects including depth sensing technology, specifications, ranging capability, accuracy, ambient light adaptability, real-time performance, hardware complexity, and typical application scenarios. The goal is to present an objective, balanced assessment of both solutions, including their respective advantages and limitations.

1. Key Specification Differences

Aspect	MRDVS S11	RealSense D435
Product Image		
Depth Technology	dToF (Direct Time-of-Flight)	Stereoscopic (Active Stereo)
Illumination Wavelength	940nm	~850nm
Detection Range	0.1 ~ 6m	0.3 ~ 3m (ideal)
Minimum Distance	~10cm	~28cm
Accuracy*	±1 cm @ 2m; ±2 cm @ 6m	<2% at 2m (~4cm)
Depth FoV	140° × 56°	87° × 58°
Depth Frame Rate	Up to 20fps (typ. 10fps)	Up to 30 fps @ 1280×720; 90 fps @ 480×270

Depth Resolution	240 × 96	Up to 1280 × 720
RGB FoV	120° × 110°	69° × 42°
RGB Resolution	1280 × 1080	1920 × 1080
RGB Sensor	Rolling Shutter	Global Shutter
Interface	Ethernet / USB	USB-C 3.1
Dimension	90 × 25 × 25 mm	90 × 25 × 25 mm
Operating Temp	-20°C ~ 60°C (Industrial)	0°C ~ 35°C (Consumer / Non-industrial)
IP Rating	IP54	None
Typical Power Consumption	≈ 2.5 W	≈ 2.5~3 W (varies with resolution)

*For the MRDVS dToF camera S11, the full-range accuracy degrades gradually with distance and depends on object reflectivity and surface roughness. However, it remains largely unaffected by indoor or outdoor lighting conditions.

Regarding latency comparison: Direct time-of-flight measurement enables per-frame depth calculation with minimal processing overhead. Theoretical end-to-end latency is therefore expected to be lower than that of stereo solutions, though actual performance will depend on the host system configuration. For the S11, the typical end-to-end latency is approximately 70~100 ms under standard operating conditions.

2. Depth Technology

S11: Uses Direct Time-of-Flight (dToF). It emits pulsed infrared light (940nm) and measures the time each pulse takes to return to the sensor, directly converting this into distance. Every pixel within the Field of View returns a depth value.

D435: Uses active stereo vision. It employs two global shutter infrared cameras to capture images and calculates depth by triangulating disparities between them. An infrared projector is integrated to project a pseudo-random speckle pattern onto the scene, enhancing feature matching in low-texture environments such as white walls.

3. Measurement Distance

S11: Specified for an operating range of 0.1 to 6 meters. Since its depth calculation does not depend on a physical baseline, accuracy degrades gradually with increasing distance. Near-field detection works down to ~10 cm.

S11 point cloud sample on black object at 10cm distance (The point cloud is largely complete, with slight elevation in the middle and missing data at the edges.)

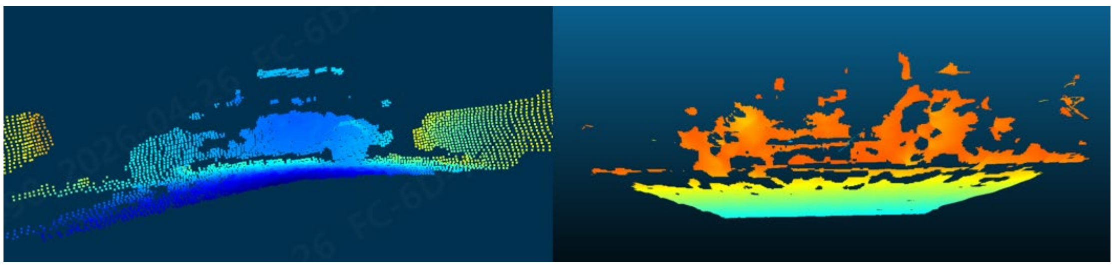
D435: Performs optimally between approximately 0.3 and 3 meters. Beyond this range, the disparity between the two stereo images becomes smaller, leading to a more noticeable increase in depth error due to its fixed baseline.

4. Environmental Light Adaptability

S11: Demonstrates strong resistance to ambient light, including sunlight and artificial lighting. The 940nm wavelength experiences less solar interference, and the sensor is specified for operation up to 100kLux, providing consistent performance across varied lighting conditions including direct sunlight.

D435: Can experience degraded performance under strong ambient light, particularly direct sunlight, as intense infrared components may overwhelm its ~850nm projected pattern. In overcast, shaded, or controlled indoor lighting environments, its performance remains stable.

Outdoor test scenario – Black vehicle detection



In this extreme outdoor scenario, neither sensor captures a fully complete point cloud on the vehicle body. However, the S11(the left) retains significantly more point cloud data compared to the D435(the right), which shows extensive data loss and higher noise levels.

5. Accuracy and Resolution

S11: Provides consistent absolute accuracy of approximately 1 centimeter across its specified range (0.1-6m). Its depth resolution in the near field is comparatively lower due to limitations of SPAD array density.

D435: Achieves sub-millimeter accuracy at very close distances (e.g., <0.5 m), making it well-suited for fine-detail capture. At longer distances (beyond 3m), disparity error grows and absolute depth accuracy degrades. It offers higher RGB lateral resolution (1920×1080) compared to the S11 (1280×1080).

Aspect	MRDVS S11	RealSense D435

Pixel Validity	Every pixel returns a depth value	Invalid points (holes) occur on textureless, reflective, or black surfaces
Resolution Concept	Lower effective pixel count but 100% valid	Higher potential resolution but valid percentage varies with scene texture
Near-Field Detail	Lower resolution at very close range	Sub-millimeter accuracy achievable at close range

Depth Data Validity Comparison

6. Typical Application Scenarios & Suitability Summary

6.1 Typical Application Scenarios

S11: Commonly selected for mobile robot obstacle avoidance (including AGV and AMR), cleaning robots, and service robot navigation, where consistent performance over varying distances, surface types (including black objects), and lighting conditions (including outdoor) is beneficial.

D435: Often used in applications requiring close-range, high-detail depth sensing, such as 3D scanning, facial recognition development, and bin-picking, particularly when scene texture is controllable, and where higher RGB resolution and high frame rate are beneficial.

6.2 Application Suitability Summary

The table below highlights preferred sensors for specific requirements, acknowledging that both have strengths.

Priority / Requirement	Better Suited	Notes
Outdoor / direct sunlight operation	S11	D435 may degrade under strong IR light

High-speed motion capture (>30 fps)	D435	Up to 90 fps (at reduced resolution)
Close-range sub-mm detail (<0.5 m)	D435	Stereo excels with textured objects at close range
Minimum detection distance	S11	Works down to 10 cm (D435 has a 28 cm minimum distance)
Hole-free depth on uniform / black surfaces	S11	Active stereo often fails on textureless areas
Glass / transparent obstacles	Neither	Consider ultrasonic or LiDAR
Mirror surfaces	Neither	Consider mechanical bumper or floor-mounted LiDAR
Dusty / foggy environments	Neither	D435 slightly less affected
Highly reflective objects	S11 (with tuning)	D435 suffers from pattern washout
Multi-sensor operation (fleet)	S11 (with hardware sync)	D435 interference is severe
Industrial temperature (-20°C to 60°C)	S11	D435 is specified for 0–35°C
IP-rated protection (dust/water)	S11	IP54 vs. none
Ethernet interface (long cable, industrial bus)	S11	D435 is USB only

Development ecosystem / SDK & community	D435	Mature ROS, OpenCV, and Python support
Technical support & timely response	S11	Direct engineering support from MRDVS
Batch customization (OEM/ODM)	S11	S11 supports hardware/software customization for volume orders

6.3 Selection Guidelines

Consider S11 when you need:

- Stable operation outdoors or under direct sunlight
- Hole-free depth on uniform, textureless, or black surfaces
- Minimum detection distance down to 10 cm
- Industrial temperature range (-20°C to 60°C) and IP-rated protection
- Ethernet interface and batch customization support

Consider D435 when you need:

- High frame rate motion capture (>30 fps, up to 90 fps at reduced resolution)
- Sub-mm close-range detail (<0.5 m)
- Higher RGB and depth resolution (up to 1280×720 depth, 1920×1080 RGB)
- Mature development ecosystem (ROS, OpenCV, Python)

7. Multi-Sensor Interference (Multiple Cameras on Same Robot / Fleet)

When several depth sensors operate in close proximity, their emissions can interfere.

Aspect	MRDVS S11	RealSense D435

Interference mechanism	Interference occurs when pulses from another sensor overlap in time and wavelength.	projected speckle patterns from multiple cameras can corrupt each other's disparity maps.
Severity	Low to moderate Random pulse timing or pseudo-random coding reduces collisions. Still, two S11 units facing each other may cause erroneous depth readings.	High Patterns interfere even at short distances. Holes and false depth increase rapidly.
Mitigation strategies	Sync via hardware trigger (external clock) or separate operating time slots (time-division multiplexing). Keep sensors pointing away from each other.	Use official anti-interference mode (alternating projection) or different pattern configurations (if SDK allows). Physical separation >1m or angled away.
Recommendation for multi-robot fleets	Acceptable with time-sharing.	Not recommended for dense fleets; consider switching some units to passive stereo (IR projector disabled) if ambient texture is sufficient.

8. Challenging Materials and Environmental Conditions

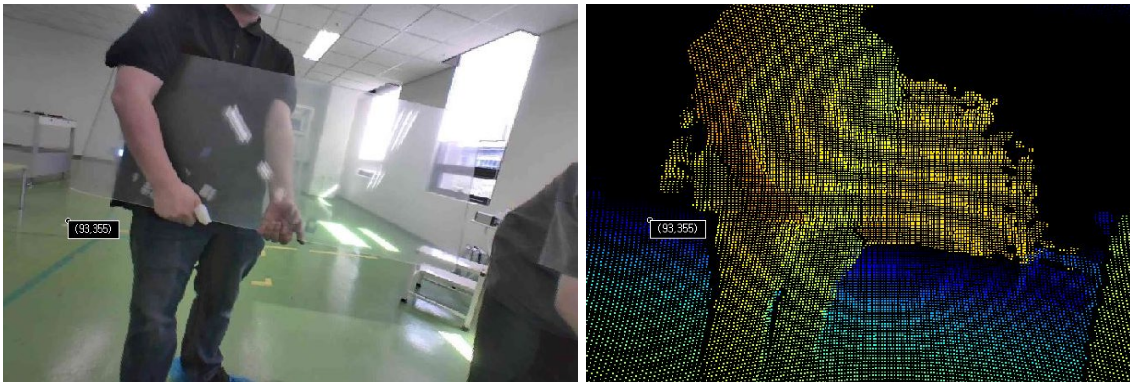
8.1 Sensor Performance Comparison

Condition / Material	MRDVS S11	RealSense D435
Glass (windows,	Partial detection	Limited detection

transparent panels)	dToF often sees glass as a weak return or range extension (signal penetrates then reflects). Depth may be erratic on clear glass.	Stereo matching struggles on transparent surfaces due to lack of projected texture. Glass typically appears as a hole or distant object.
Highly reflective objects (metals, glossy plastics)	Over-saturation can cause early returns, resulting in measured distance shorter than actual. Mitigation: gain control and multi-echo processing (if supported).	Speckle pattern becomes distorted or washed out, resulting in invalid depth holes. Performance varies significantly with angle and surface roughness.
Mirror surfaces	Direct reflection may cause range overestimation or ghost points, resulting in unreliable depth data on mirrors.	Stereo treats the mirror image as a virtual scene behind the mirror, resulting in false depth readings at a distance. No valid object detection.
Dust & airborne particles	Moderate impact Dense dust clouds can attenuate the optical signal and reduce range. Static dust on the lens primarily reduces SNR.	Low impact on depth computation, as stereo works with edges rather than intensity. However, dust on lenses degrades image sharpness and pattern contrast, resulting in more depth holes.
Fog, rain, steam	Severe attenuation Water droplets scatter and diffuse the IR pulse, causing range to collapse rapidly in thick fog or heavy rain.	Less affected Stereo matching still works on visible edges, though fog reduces overall contrast. Rain droplets close to the lens may create false disparities.

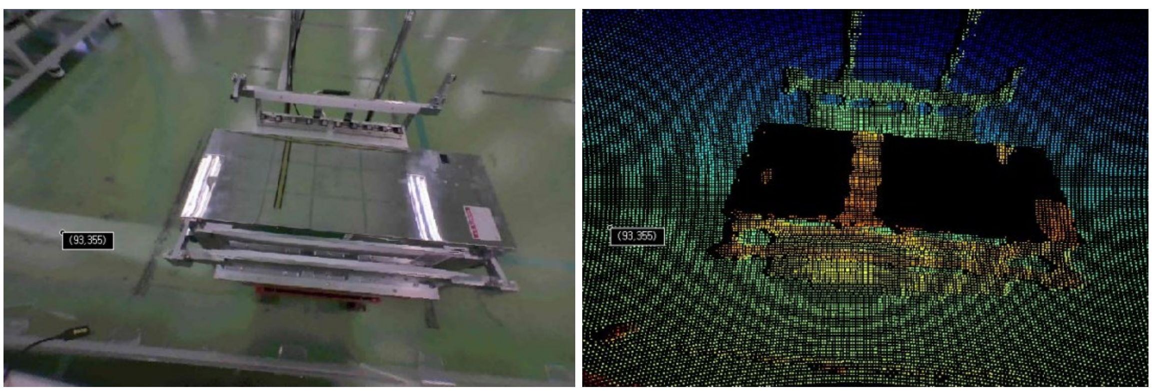
8.2 Practical recommendations

For glass detection: neither sensor is reliable. Add ultrasonic or acoustic sensors, or use structured light with a wavelength that reflects from glass.



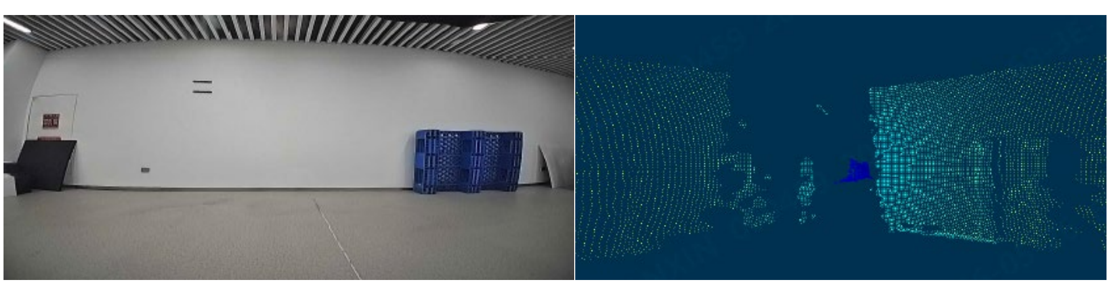
S Series data sample on glass surface - for reference only

For mirrors, highly polished floors, or metal surfaces: avoid relying on either depth sensor. Use a mechanical bumper or 2D LiDAR at a low height.

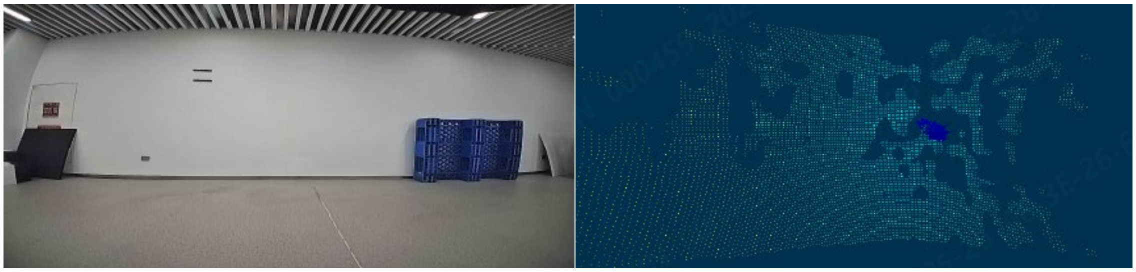


S Series data sample on metal surface - for reference only

For dusty or foggy environments (e.g. agricultural robots, outdoor emergency response): consider LiDAR (mechanical or solid-state) instead of either camera. Between the two, D435 has a slight edge in light fog, but neither is robust.



The image above shows S11 point cloud data captured in a dusty environment (The imaging exhibits noise, and partial point cloud loss is observed on background white walls)



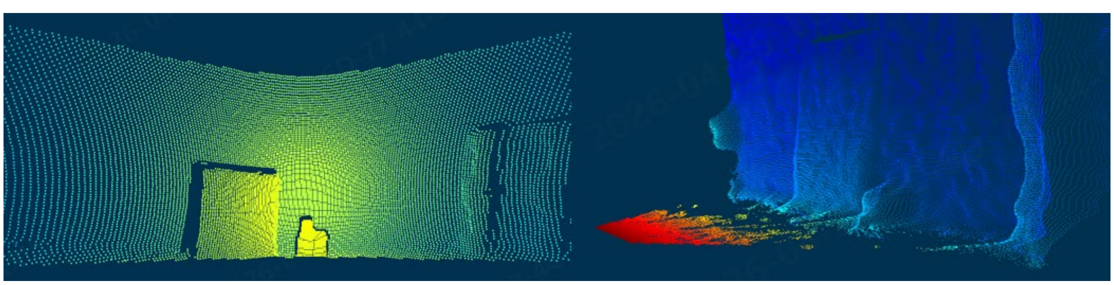
The image above shows S11 point cloud data captured in a water mist environment. Imaging fluctuation with partial data loss on background white walls.

For reflective objects: S11 can be tuned with multi-frame averaging and exposure control; D435 may benefit from oblique camera angles.

9. Mobile Robot Common Scenario Test Comparison

Test 1 - Black board near white wall

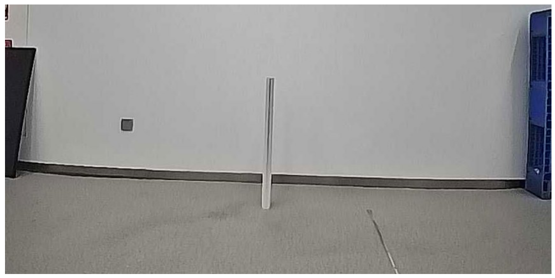
Indoor test scenario - Black board placed near a white wall



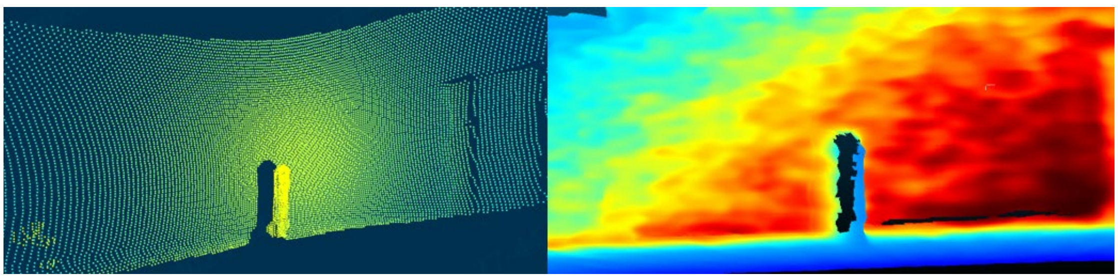
The S11(the left) captures a complete and clear depth image with well-defined edges separating the board from the wall.

The D435(the right) shows significant blending between the board and the wall, resulting in poor edge definition and unclear object separation.

Test 2 - Reflective column and surrounding environment



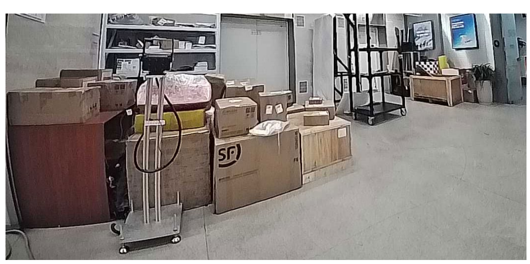
Reflective column and surrounding environment



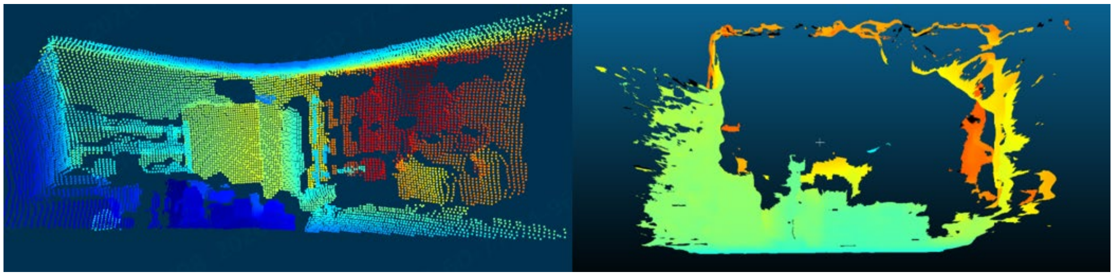
The S11(the left) produces a complete depth image with no missing or dispersed data at the column edges.

The D435(the right) shows minor edge loss with small missing portions around the reflective surface.

Test 3 - Indoor multiple objects



Indoor multiple objects with significant depth variation and stacking



The S11(the left) produces a clear point cloud with well-retained details throughout the scene.

The D435(the right) shows substantial point cloud loss and blank areas in the most complex regions where objects overlap and stack.

F.2 3D Vision Sensors Selection Guide

How to Choose Between Stereo Vision, Structured Light, iToF, and dToF

Update on 9th May. 2026

To help users make informed decisions when choosing among various 3D vision hardware solutions, we have compiled this document for your reference, providing a general analysis of the principles, advantages, disadvantages, and application scenarios of the four mainstream 3D vision sensors: Stereo Vision, Structured Light, iToF, and dToF.

Please note that the descriptions of different technologies in this document are based on their underlying principles and general performance characteristics, and do not represent any specific manufacturer's product. Different camera manufacturers may optimize their products using different chips, algorithm enhancements, or hybrid approaches, which could result in performance that differs from the general descriptions provided here. Feedback and corrections are always welcome.

I. Stereo Vision (Passive and Active)

A passive ranging technology that mimics the human eye's disparity principle. It is divided into passive stereo and active stereo.

Working Principle

Stereo depth reconstruction uses triangulation to calculate the distance from the object being measured to the camera. When two cameras observe the same object, the positional difference of the object in the two images is called disparity. The closer the object is to the camera, the larger the disparity; the farther away, the smaller the disparity.

Given the known relative positional relationship (e.g., the distance between the two cameras), the distance can be calculated using similar triangle principles.

	Passive Stereo	Active Stereo
Principle	Relies solely on natural texture from ambient light; calculates disparity through image matching	Adds an infrared laser projector (dot matrix/speckle/line) to actively project texture, enhancing matching in low-texture areas
Advantages	Low cost, low power consumption, no active light interference, multiple devices can work simultaneously	Usable in low-light or textureless scenes; more stable performance than passive stereo
Disadvantages	Essentially unusable on low-texture surfaces (white walls) or in low-light conditions	Projection patterns interfere with each other when multiple devices work together, causing matching failures; pattern is easily overwhelmed by strong outdoor sunlight, degrading depth performance
Typical Representatives	Stereolabs ZED series, Senseno	RealSense D400 series, Luxonis OAK series, Orbbec Gemini series

Active stereo is an enhanced version of passive stereo. The infrared fill light solves the pain points of low-light and low-texture conditions. However, it does not fundamentally improve issues such as long-range accuracy or strong light interference. Active stereo still suffers from the inverse-square degradation of accuracy inherent to triangulation methods. Furthermore, when multiple active stereo devices operate simultaneously, projected patterns interfere with each other, leading to matching failures.

II. Structured Light

An active triangulation technique that actively projects a coded pattern and directly solves for depth through pattern deformation.

Working Principle

Structured light is an active triangulation measurement technique, belonging to the same broader category as active stereo vision.

The working method is as follows: an infrared laser projector casts a structured light pattern containing coded information (such as stripes, grids, or pseudo-random dot arrays) onto the object being observed. These patterns deform (e.g., stripes bend, dots shift) according to the object's geometry and distance. An infrared camera captures these deformed patterns, and the system decodes the degree of deformation to directly calculate the depth information for each pixel.

Core Difference from Active Stereo

Aspect	Active Stereo	Structured Light
Depth Calculation	Calculates disparity by matching corresponding points in left and right images, relying on correspondence between images	Directly obtains depth by decoding pattern deformation; each projected feature point carries its own "identity tag" and does not rely on stereo matching

Core Advantages

- Active light source adds texture: Solves the pain points of passive stereo in low-texture and low-light scenes.
- Extremely high close-range accuracy: Can achieve sub-millimeter accuracy (e.g., Apple Face ID module).
- No need for stereo matching: Each projected feature point carries coded information, providing a more direct computational path.

Technical Limitations

- Limited measurement range: Optimal operating distance is typically 0.3–3 meters; long-range accuracy degrades with the square of the distance.
- Multi-path interference: Multiple reflections in complex scenes can cause depth calculation errors.
- Interference from similar devices: When multiple structured light devices work simultaneously, their projected patterns interfere with each other, making decoding impossible.
- Sunlight interference: In strong outdoor light, the projected pattern is easily overwhelmed by ambient light, limiting operation.

Typical Representatives

- Consumer grade: Apple Face ID module, Orbbec Astra series (mainly used for close-range face recognition, 3D modeling, etc.).
- Industrial grade / hybrid solutions: Photoneo MotionCam-3D series, Mech-Mind Mech-Eye series, Zivid products.

III. iToF (Indirect Time-of-Flight)

A ranging technique that indirectly calculates flight time through phase difference.

Working Principle

iToF (indirect Time-of-Flight) collects energy values at different time windows, analyzes the proportion between these values, and indirectly measures the time difference between the transmitted and received signals. It is mainly divided into two modulation methods:

- CW-iToF (Continuous Wave): Uses sinusoidal wave modulation. The phase shift between the received and transmitted sinusoidal waves is proportional to the object's distance. Accuracy is limited by random noise and quantization noise. To improve accuracy, high-power, short-integration-time sampling combined with high modulation frequency is typically used.

- PL-iToF (Pulse Modulation): Emits light pulses with amplitude and time information. Uses dual-sampling techniques to improve accuracy. The calculation is simpler and has lower computational load, but accuracy is weaker than CW-iToF, and it is more sensitive to background noise.

Core Advantages

- Mature chip industry chain.
- Good real-time performance.

Technical Limitations

- Flying pixels: At object edges, a single pixel simultaneously receives reflected light from both the foreground and background, resulting in incorrect depth values and generating "floating invalid points in the air."
- Multi-path interference (MPI): In real-world scenes, complex diffuse or specular reflections cause light to be reflected multiple times before reaching the sensor, leading to systematically overestimated measurements. This has been the biggest technical obstacle plaguing iToF for many years.
- High sensitivity to black objects: Black objects have strong light absorption and weak reflected signals, causing a sharp drop in signal-to-noise ratio. Depth data easily develops holes or becomes invalid, making it difficult to stably detect dark-colored targets.
- Severe multi-device interference: When multiple iToF devices operate simultaneously in the same area, their modulated signals interfere with each other, causing large-scale errors or complete failure of depth data, limiting deployment in dense cluster scenarios.

Typical Representatives

- iToF chip manufacturers: Sony, Infineon, PMD.
- Module manufacturers: Lucid Helios2 series, SICK Visionary-T Mini, MRDVS M series, IFM 3D cameras.

IV. dToF (Direct Time-of-Flight)

The ultimate ranging technique that directly measures the round-trip time of photons.

Working Principle

dToF (direct Time-of-Flight) technology directly measures the time difference between emitting and receiving a light pulse. Due to laser safety limits and consumer product power constraints, the pulse energy emitted by ToF cameras is limited. By the time the light returns to the receiver, the energy density has decreased by more than a trillion times. Ambient light acts as noise, severely interfering with signal detection.

Therefore, dToF requires extremely sensitive photodetectors: Single-Photon Avalanche Diodes (SPADs). When a SPAD is in operation, it is biased with a high reverse voltage. When a photon is absorbed and converted into a free electron, the strong internal electric field accelerates this electron, which collides to generate more carriers, creating a geometrically amplified avalanche effect, thereby outputting a large current pulse and achieving single-photon detection.

dToF uses the Time-Correlated Single-Photon Counting (TCSPC) method to achieve picosecond-level time precision. The system repeats the emission-detection of the same pulse signal thousands to hundreds of thousands of times, obtains a statistical distribution histogram from each detection, reconstructs the curve of light pulse energy over time, and thus derives the precise flight time.

Core Advantages

- Distance accuracy: Within the normal operating range, error does not significantly amplify with increasing distance, maintaining centimeter-level accuracy at medium-to-long ranges.
- Multi-path interference suppression: Directly measures the arrival time of the first wave, making it much less affected by multi-path reflections than iToF.

- Low power consumption and high efficiency: A single pulse completes the distance measurement, with extremely low computational load and lower latency.
- Ambient light adaptability: Uses time-gating technology combined with narrow-band filters and near-infrared light sources (typical wavelength 940nm), enabling effective depth data acquisition under high ambient light conditions up to 100kLux.
- Multi-device collaboration friendly: Pulse timing of different devices can be staggered (e.g., using time-division or pulse coding), natively supporting simultaneous operation of multiple devices.
- Real-time performance: No need for complex matching algorithms; depth data can be output directly, with typical frame rates of 10–20 fps.

Technical Challenges (Gradually Improving)

- SPAD Dark Count Rate (DCR): Improved compared to early solutions through 3D stacking processes and quenching circuit optimization.
- Photon Detection Efficiency (PDE): The application of BSI (backside illumination) technology has improved photosensitivity.
- On-chip integration: With advances in advanced process nodes, SPAD arrays, TDCs (Time-to-Digital Converters), and histogram algorithms can now be integrated on-chip.
- Relatively low spatial resolution: Limited by the physical size of SPADs and the complexity of backend counting circuits (TDCs), resolution is generally lower than iToF.

Typical Representatives

- Consumer/mobile: Apple LiDAR (iPad Pro/iPhone Pro series).
- Industrial grade: RoboSense E1/E1R, MRDVS S series.