HESAI

www.hesaitech.com

AT128E2X

128-Channel Hybrid Solid-State Lidar User Manual

Classification: Internal
Doc Version: A01-en-230920

Table of Contents

About this manual

Please make sure to read through this user manual before your first use and follow the instructions herein when you operate the product. Failure to comply with the instructions may result in product damage, property loss, personal injuries, and/or a breach of warranty.

Access to this manual

To obtain the latest version, please try one of the following:

- Visit the Download page of Hesai's official website: https://www.hesaitech.com/downloads/
- Contact your sales representative at Hesai.
- Contact Hesai's technical support team: service@hesaitech.com

Technical support

If your question is not addressed in this user manual, please contact us at:

- service@hesaitech.com
- https://www.hesaitech.com/technical-support/
- https://github.com/HesaiTechnology (Please leave your questions under the corresponding GitHub projects.)

Legends

Warnings: Instructions that must be followed to ensure safe and proper use of the product.

Notes: Additional information that may be helpful.

Formatting

Monospace font: field names

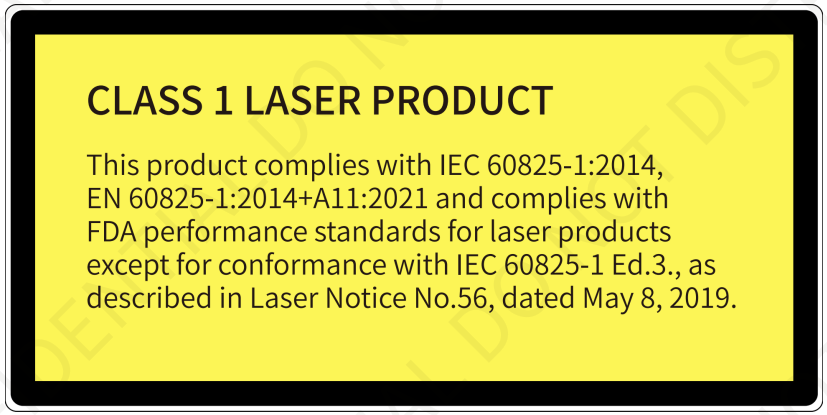
For example: `Distance` represents the Distance field.

Safety notice

- Please check the certification information on the product's nameplate and read through the corresponding certification warnings. If specific users require not to present certification information on the nameplate, please follow the agreed-to arrangements.
- If you incorporate this lidar product into your product(s), you are required to provide this user manual (or the means to access this user manual) to the intended users of your product(s).
- This lidar product is intended as a component of an end product. It is the responsibility of the end-product supplier to assess the risk of use in accordance with applicable standards and inform the intended user of safety-related information.
- Should there be other agreements with specific users, the other agreements shall apply.
- Before using a product, please confirm with Hesai the development maturity of the product in a timely manner. For products still in development, Hesai makes no warranty of non-infringement nor assumes any responsibility for quality assurance.

Special warnings

Laser safety



Hot surface

Hot parts!
Burned fingers when handling the parts.
Wait one-half hour after switching off before handling the parts.

Abnormalities

In any of the circumstances listed below, stop using the product immediately:

- If you suspect malfunctions of or damage to the product. For example, the product generates significant noise or is visibly vibrating.
- If you or people in the nearby environment feel discomfort.
- If any device or equipment in the nearby environment malfunctions.
  Meanwhile, contact Hesai Technology or an authorized Hesai Technology service provider for more information on product disposal.

Prohibition of disassembly

Unless expressly agreed to in writing by Hesai Technology, do NOT disassemble the product.

Operating environment

Radio frequency interference

- Before using the product, make sure to read all the signs and notices on the product enclosure (including the bottom plate).
- Although the product is designed, tested, and manufactured to comply with the regulations on RF radiation (such as FCC, CE-EMC, or KCC), the radiation from the product may still influence electronic devices.

Vibration

- If significant mechanical shocks and vibration exist in the product's operating environment, please contact Hesai's technical support team to obtain the shock and vibration limits of your product model. Exposure to over-the-limit shocks or vibration may damage the product.
- Make sure to package the product in shock-proof materials to avoid damage during transport.

Explosive atmosphere and other air conditions

- Do NOT use the product in any area where potentially explosive atmospheres are present, such as environments with high concentrations of flammable chemicals, vapors, or particulates (including particles, dust, and metal powder) in the air.
- Do NOT expose the product to environments having high concentrations of industrial chemicals, including liquefied gases that are easily vaporized (such as helium). Such exposure can damage or impair product functionality.

Chemical environment

To prevent damage or impairment of product functionality, do NOT expose the product to corrosive liquids, including but not limited to strong acids, strong bases, esters, and ethers.

Ingress protection

Please check the product's user manual for its IP rating (refer to Section 1.4 Specifications). Make sure to avoid any ingress beyond that rating.

Operating temperature

Please check the product's user manual for its operating temperature (refer to Section 1.4 Specifications). Make sure not to exceed the operating temperature range.

Recommended storage conditions

Please store the product in a dry and well-ventilated place. The recommended ambient temperature is 23 ± 5°C, and the humidity is between 30% and 70%.

Light interference

Certain precision optical instruments may interfere with the laser light emitted from the product. Please check all the instructions for these instruments and take preventive measures if necessary. For example, protective leather covers are provided for certain product models; when such products are temporarily not used for measurement, the leather covers can be applied to block laser light emission.

Personnel

Recommended operator qualifications

The product should be operated by professionals with engineering backgrounds or experience in operating optical, electrical, and mechanical instruments. Please follow the instructions in this manual when operating the product and contact Hesai technical support if needed.

Medical device interference

- Some components in the product can emit electromagnetic fields. If the product operators or people in the nearby environment wear medical devices (such as cochlear implants, implanted pacemakers, and defibrillators), make sure to consult the physicians and medical device manufacturers for medical advice, such as determining whether keeping the product a safe distance away from the medical devices is needed.
- If you suspect that the product is interfering with your medical device, stop using the product immediately.

Installation and operation

Power supply

- You are recommended to use only the cables and power adapters provided by Hesai Technology.
- If you are to design, configure, or select the power supply system (including cables) for the product, make sure to comply with the electrical specifications in the product's user manual (refer to Section 1.4 Specifications and the Power Supply Requirements section if available); for technical support, please contact Hesai Technology. Do NOT use off-spec or damaged cables or adapters.

Electrical interface

- Before powering on the product, make sure the electrical interfaces are dry and clean. Do NOT power on the product in humid conditions.
- Please check the Interfaces section in the product's user manual and strictly follow the instructions on plugging/unplugging the connector. If abnormalities already exist (such as bent pins, broken cables, and loose screws), stop using the product and contact Hesai technical support.
- To prevent breakdowns, turn off the power source before connection and disconnection.

Eye safety

The product is a Class 1 laser product. It satisfies the requirements of:

- IEC 60825-1:2014
- EN 60825-1:2014+A11:2021
- 21 CFR 1040.10 and 1040.11 except for deviations (IEC 60825-1 Ed.3) pursuant to Laser Notice No.56, dated May 8, 2019.

CAUTION: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

CAUTION

- For maximum self-protection, it is strongly warned NOT to look into the transmitting laser through a magnifying product (microscope, eye loupe, magnifying glass, etc.).
- This product does not have a power switch. It starts operating once connected to power. During operation, the entire optical window can be regarded as the product's laser emitting window; looking at the optical window can be regarded as looking into transmitting laser.

Product enclosure

- The product contains metal, glass, plastic, as well as sensitive electronic components. If the product is dropped or burnt, stop using it immediately and contact Hesai technical support.
- Do NOT squeeze or pierce the product. If the product enclosure is broken, stop using it immediately and contact Hesai technical support.
- Certain product models contain high-speed rotating parts. To avoid potential injuries, do NOT operate the product if the enclosure is loose.
- Before operating the product, make sure it is properly and securely mounted. The mounting should prevent the product from leaving its mounting position under external forces (such as collisions, high winds, and stone impacts).
- If the product enclosure consists of fins or grooves, please wear gloves when handling the product. Applying too much pressure with your bare hands may cause cuts, bruises or other injuries.

Product enclosure: optical window

- Do NOT apply protective film, wax or any other substance on the optical window.
- To keep the product's optical window from fingerprints and other stains, do NOT touch the optical window with bare hands. If the optical window is already stained, please refer to the cleaning method in the Sensor Maintenance section of the user manual.
- To prevent scratches, do NOT touch the product's optical window with hard or sharp objects. If scratches already exist, stop using the product and contact Hesai technical support. Severe scratches may affect the quality of the product's point cloud data.
- Before installing any exterior part, please ensure that each exterior part and its movable area do not overlap the Field of View (FOV) of the lidar product.

The FOV of lidar is the spatial angular range bounded by the horizontal and vertical FOV ranges (see Section 1.4 Specifications of the product's user manual); the distance to the origin of the lidar's coordinate system is not limited. For inquiries about the FOV, please contact Hesai technical support.

Hot surface

During operation or a time period after the operation, the product's enclosure can be hot.

- To prevent discomfort or even burns, do NOT touch the product's enclosure with your skin.
- To prevent fires, do NOT keep flammable materials away from the product's enclosure.
- If a hot surface sign is provided on the product's enclosure, the product will be embedded into other equipment. Please make sure the sign is not blocked from view. In case the sign is not visible from the outside, make sure to take effective measures to warn any third party of the hot surface hazards.

Certain product models support active heating of the optical window to reduce the impact of ice and frost. Users can turn off this function.

- While active heating is ON, please avoid direct skin contact with the optical window.
- For each product model, the location of the optical window is illustrated in the Introduction section of the product's user manual.

Peripherals

The product may be used along with accessories and devices, such as suction cup mounts, extension cables, power supplies, network devices, GPS/PTP devices, and cleaning equipment. Please refer to all relevant specifications in the product's user manual, or contact Hesai technical support. Using off-spec or unsuitable devices may result in product damage or even personal injuries.

Firmware and software upgrading

Make sure to use only the upgrade files provided by Hesai Technology. Make sure to observe all the instructions provided for that upgrade file.

Customized firmware and software

- Before using a customized version of firmware and software, please fully understand the differences in functions and performance between the customized version and the standard version.
- Make sure to strictly follow all the instructions and safety precautions provided for that customized version. If the product does not function as anticipated, stop using the product immediately and contact Hesai technical support.

Point cloud data processing

- Certain product models support one or more point cloud data processing functions, including but not limited to: Noise Filtering, Interstitial Points Filtering, Retro Multi-Reflection Filtering, and Non-Linear Reflectivity Mapping.
- These functions are configurable and are intended only to assist the user in extracting information from the point cloud data. Users are in full control of whether to use any of these functions. Moreover, users are responsible for analyzing the product's intended application scenarios and evaluating the risk of enabling one or more of these functions in combination.
- To learn about the supported functions of a product model, please contact Hesai technical support.

Repair and maintenance

For product repair or maintenance issues, please contact Hesai Technology or an authorized Hesai Technology service provider.

Repair

Unless expressly agreed to in writing by Hesai Technology, do NOT by yourself or entrust any third party to disassemble, repair, modify, or retrofit the product. Such a breach:

- can result in product damage (including but not limited to water resistance failure), property loss, and/or injuries;
- shall constitute a breach of warranty.

1. Introduction

1.1. Operating principle

Distance measurement: Time of Flight (ToF)

1. A laser diode emits a beam of ultrashort laser pulses onto the target object.
2. The laser pulses are reflected after hitting the target object. The returning beam is detected by an optical sensor.
3. Distance to the object can be accurately measured by calculating the time between laser emission and receipt.

$$d = \frac{ct}{2}$$

d: Distance
c: Speed of light
t: Travel time of the laser beam

1.2. Lidar structure

The lidar structure is shown in Figure 3. Mirror rotation direction (top view). A rotating mirror is used to scan horizontally.

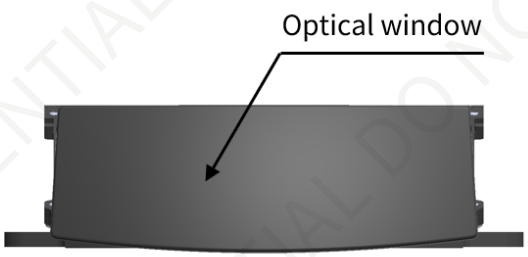


Figure 1. Front view

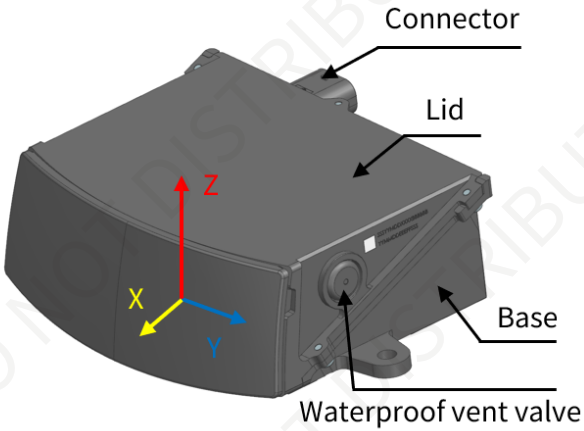


Figure 2. Coordinate system (isometric view)

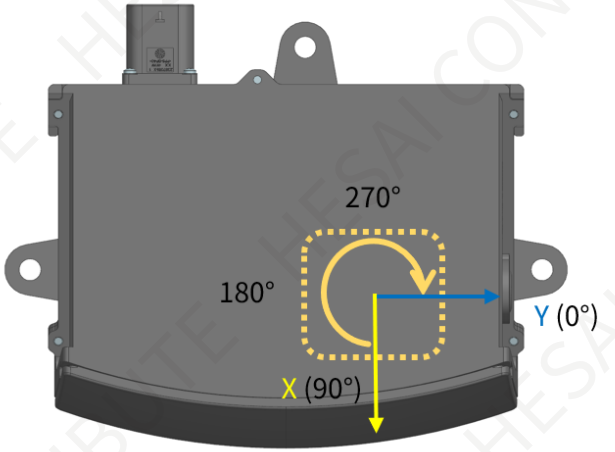


Figure 3. Mirror rotation direction (top view)

- The lidar's coordinate system is illustrated in Figure 2. Coordinate system (isometric view). The Z-axis is the axis of rotation.
- The origin is shown in Figure 5. Origin of coordinates (unit: mm). All measurements are relative to the origin.
- The mirror rotates clockwise in the top view, see Figure 3. Mirror rotation direction (top view).
- Lidar azimuthal position is defined in Figure 3. Mirror rotation direction (top view). The Y-axis corresponds to 0°.

1.3. Channel distribution

- The designed vertical resolution is 0.2° across the FOV, as shown in Figure 4. Channel vertical distribution and detailed in Appendix A Channel distribution data.
- Each channel has an intrinsic angle offset, both horizontally and vertically. The offset angles are recorded in this lidar unit's angle correction file (see Appendix C Angle correction).

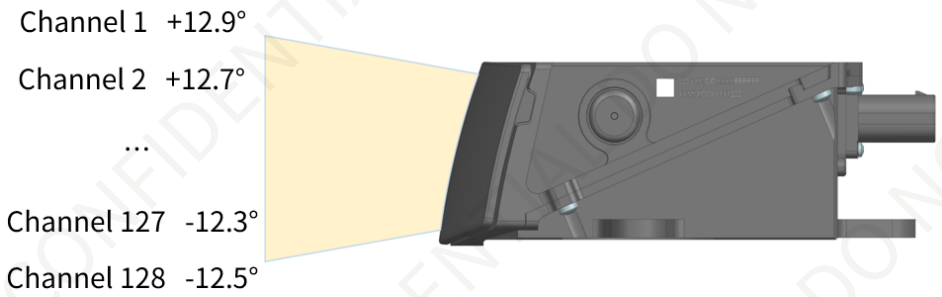


Figure 4. Channel vertical distribution

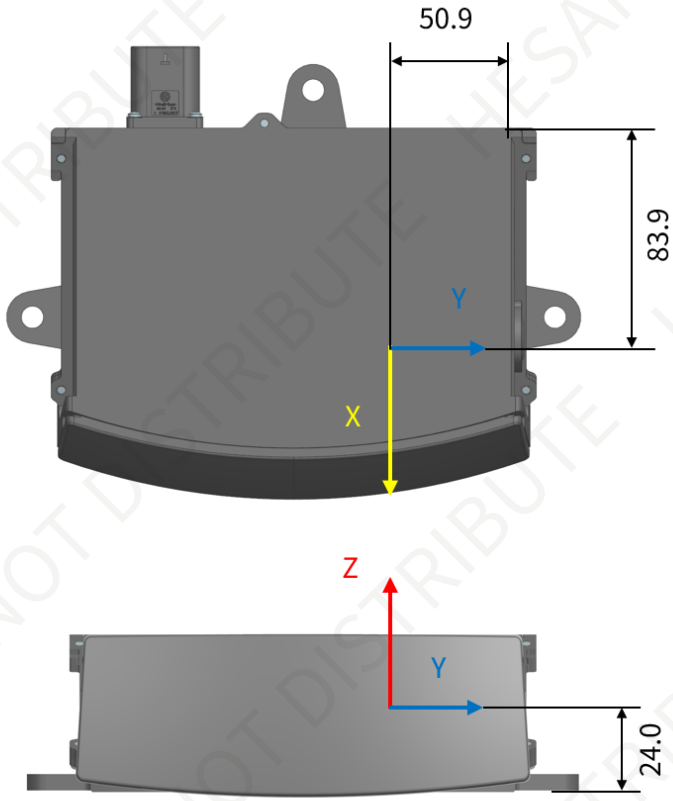


Figure 5. Origin of coordinates (unit: mm)

1.4. Specifications

SENSOR

Scanning method	1-D rotating mirror (hybrid solid-state)
Channels	128
Range capability	1 to 180 m (at 10% reflectivity)
Range accuracy	±5 cm (typical)
Range precision	3 cm (1σ)
FOV (horizontal)	120°
Resolution (horizontal)	0.1° (10 Hz) 0.2° (20 Hz)
FOV (vertical)	25.4° (-12.5° to 12.9°)
Resolution (vertical)	0.2°
Frame rate	10/20 Hz
Return modes	Single Return (Last/Strongest) Dual Return (Last and Strongest)

MECHANICAL/ELECTRICAL/OPERATIONAL

Wavelength	905 nm
Laser class	Class 1 Eye Safe
Ingress protection	IP6K7 & IP6K9K
Dimensions ①	136 x 112 x 48 (WDH, mm)
Rated voltage range ②	DC 9 to 32 V

Power consumption ③	18 W
Operating temperature	-40°C to 85°C
Storage temperature	-40°C to 95°C
Weight ①	0.95 kg

DATA I/O

Data transmission	UDP/IP automotive Ethernet, 1000BASE-T1 Slave Mode
Measurements	Distance, azimuth angle and reflectivity
Valid data points ④	Single Return 1 536 000 points/sec Dual Return 3 072 000 points/sec
Point cloud data rate ⑤	Single Return 55.7/111.4 Mbps (avg/peak) Dual Return 111.4/222.8 Mbps (avg/peak)
Clock source	PTP
PTP clock accuracy	⩽1 μs
PTP clock drift ⑥	⩽5 μs/s

Specifications are subject to change. Please refer to the latest version.

Notes to the specifications

① **Dimensions and weight**	May be different for customized models. The mechanical drawings and data exclusively provided for customized models shall prevail.
② **Rated Voltage Range**	• Lidar with 24 V nominal voltage: DC 9 to 32 V. • Lidar with 12 V nominal voltage: DC 9 to 16 V. • Nominal voltage: shown on the Home page of web control (see Section 4.1 Home).
③ **Power consumption**	• Typical value, not including accessories such as the connection box. • The external power supply should be able to provide at least 45 W.
④ **Valid Data Points**	• Point cloud data points (i.e. number of returns) generated per second. • In **Single Return Mode**: ◦ Given: horizontal FOV (120°), horizontal resolution (0.1° at 10 Hz), number of channels (128), and frame rate (10 Hz). ◦ At 10 Hz, each channel generates 120/0.1 = 1200 points per frame; all channels generate 1200 * 128 = 153 600 points per frame, and 1 536 000 points (10 frames) per second. • In **Dual Return Mode**, the number of valid data points is twice that in **Single Return Mode**. • The actual horizontal FOV of each mirror surface is slightly larger than 120°, so the actual data points are slightly more than the valid data points.

⑤ **Point cloud data rate**	• In **Single Return Mode**: ◦ Given: horizontal FOV (120°), horizontal resolution (0.1° at 10 Hz), frame rate (10 Hz), size of Point Cloud Data Packets (1160 bytes) and the number of blocks in each packet (2) ◦ At 10 Hz, one return is generated for each 0.1° azimuth; thus 1200 (120°/0.1°) returns for each frame and 12000 returns (10 frames) per second. ◦ Each Point Cloud Data Packet contains two blocks, and each block stores one return. ◦ Therefore, 12000/2 = 6000 packets are transmitted per second, totaling 6000 * 1160 bytes ◦ With unit conversion, point cloud average data rate = 6000 * 1160 * 8 * 1E-6 ≈ 55.7 Mbps. • In **Dual Return Mode**, point cloud average data rate is twice that in **Single Return Mode**. • Since the duty cycle for point cloud data transmission is approximately 50%, the peak data rate is approximately twice the average data rate in the table.
⑥ **PTP clock drift**	Defined as the drift at a constant temperature after the lidar (slave clock) loses connection to the PTP master.

2. Setup

2.1. Mechanical Installation

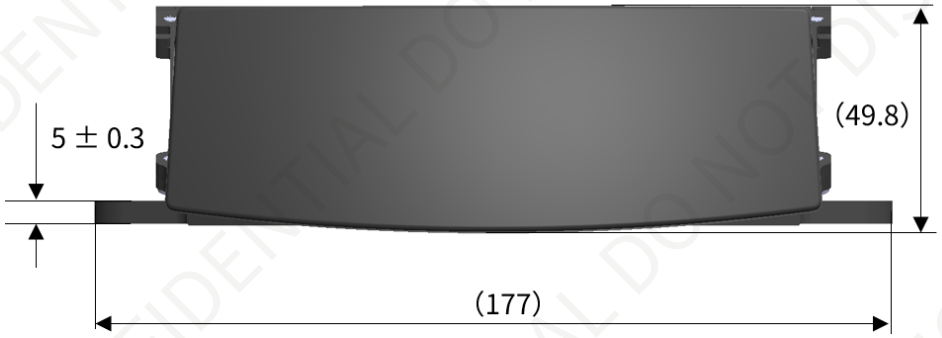


Figure 6. Front view (unit: mm)

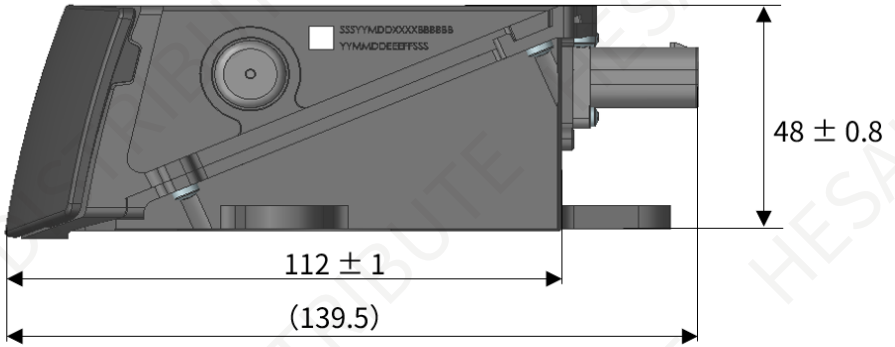


Figure 7. Right side view (unit: mm)

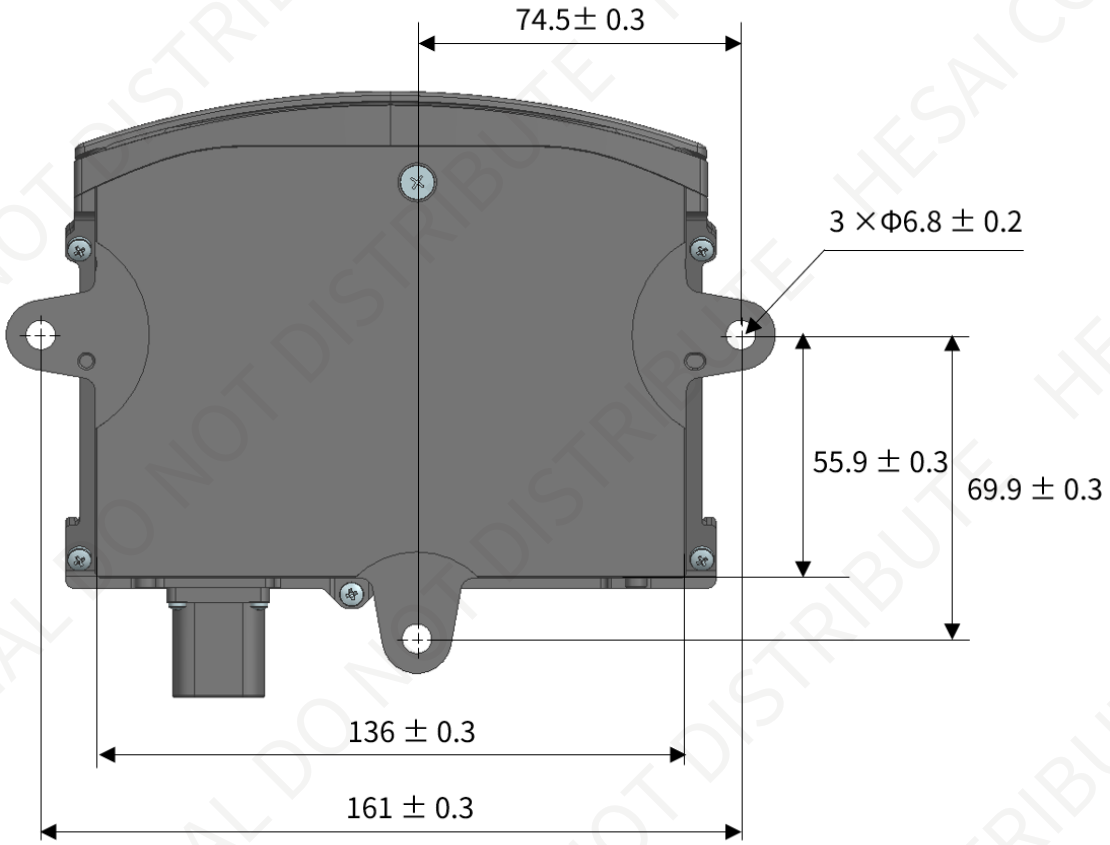


Figure 8. Bottom view (unit: mm)

The information in this section may be different for customized models. The mechanical drawings and data exclusively provided for customized models shall prevail.

2.2. Interfaces

TE Connectivity part number: 2387351-1 (male socket, on the lidar)

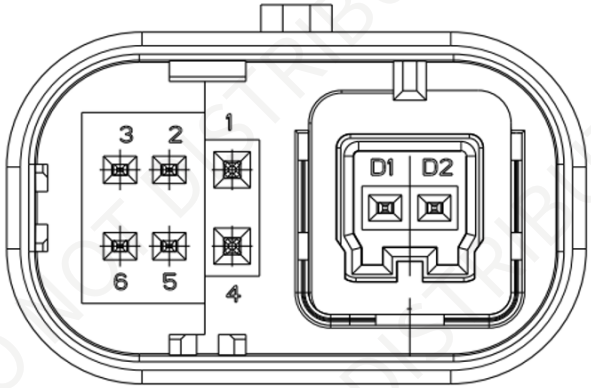


Figure 9. TE connector (male socket): dimensions and pin number

2.2.1. Pin description

No.	Signal	Voltage
1	VCC	9 to 32 V
2	-	-
3	-	-
4	GND	0 V
5	-	-
6	-	-
D2	MDI-P	-
D1	MDI-N	-

- Lidar with 24 V nominal voltage: DC 9 to 32 V.
- Lidar with 12 V nominal voltage: DC 9 to 16 V.
- Nominal voltage: shown on the Home page of web control (see Section 4.1 Home).

Avoid touching the reserved wires or ports with bare hands.

2.2.2. Connector Use

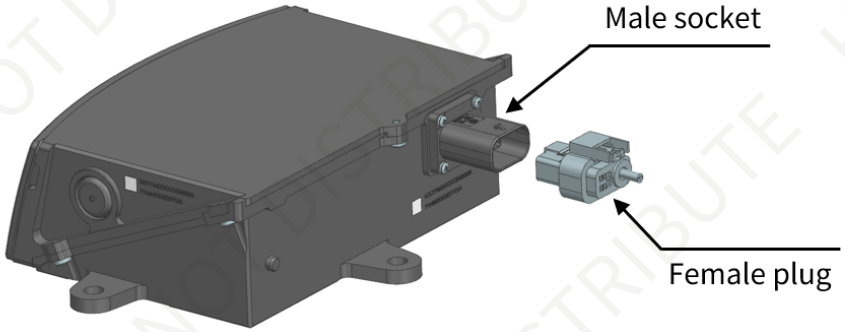


Figure 10. Connectors

Connection	Disconnection
1. Turn off the power source. 2. Make sure the plug's red locking clip is on the same side as the socket's latch. 3. Push the plug straight into the socket until a click is heard. 4. Push down the red locking clip to the bottommost position until a click is heard.	1. Turn off the power source. 2. Pull up the red locking clip with your fingernail until a click is heard. 3. Push down the black clip and pull the plug from the socket.

- DO NOT attempt to force open a connection by pulling on the cables or by twisting the connectors in any way. Doing so can loosen the connectors' shells, or even damage the contacts.
- If the connector's shell is accidentally pulled off, stop using the connector and contact Hesai technical support.
- DO NOT attempt to assemble the connector's shell and cable collet; DO NOT connect a connector without its shell. Doing so may damage

the lidar's circuits.

- Before connection, check the pins on the socket and the holes on the plug. If bent pins or damaged holes occur, stop using the connector and contact technical support.
- The connector supports at least 20 mating cycles. Exceeding this limit may result in connector damage.

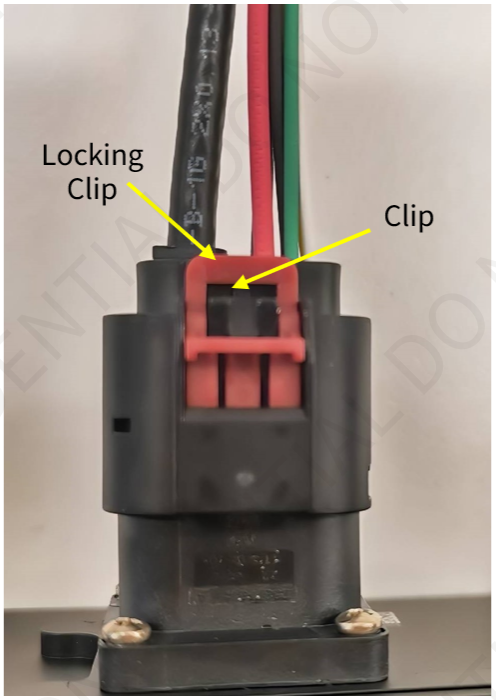


Figure 11. Connection

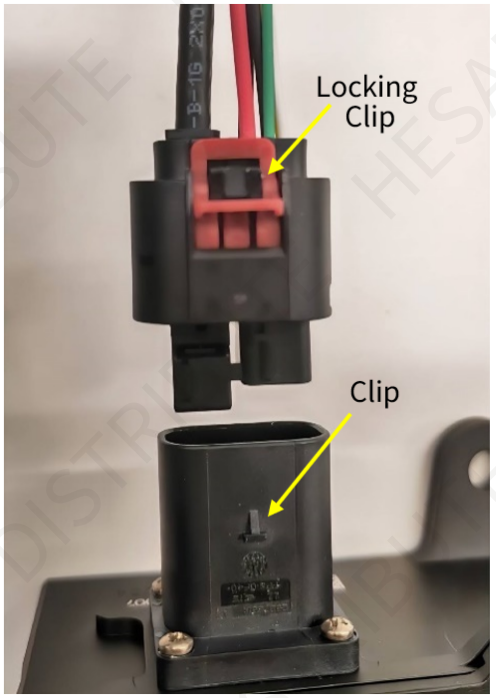


Figure 12. Disconnection

2.2.3. Cables (Ethernet)

OD (outside diameter) = 4.10 ± 0.20 mm

Minimum bend radius:
Single: 5 * OD
Multiple: 15 * OD

2.3. Connection box (optional)

Users may connect the lidar directly or using the connection box.

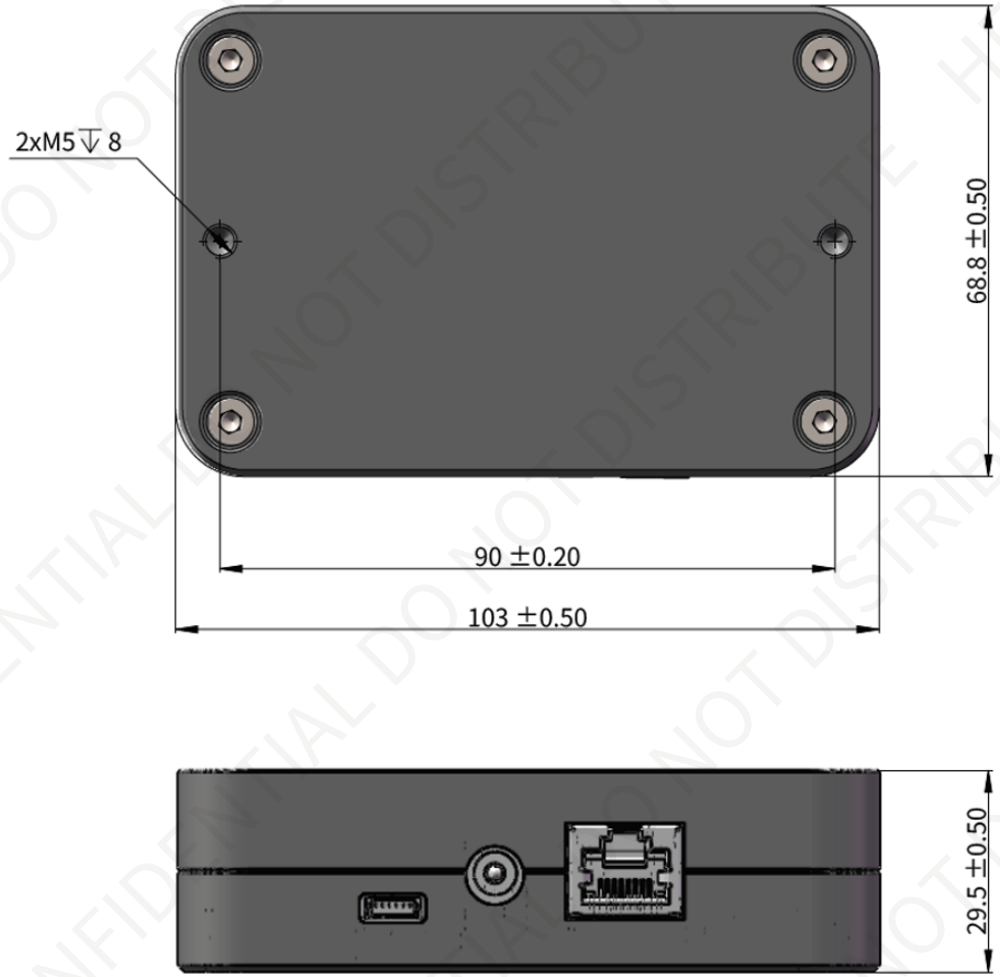


Figure 13. Connection box (unit: mm)

An additional cable is used for connecting the lidar (on the left) and the connection box (on the right), as shown below.

One cable's head cannot connect to another cable's tail, so each lidar can only use one cable.

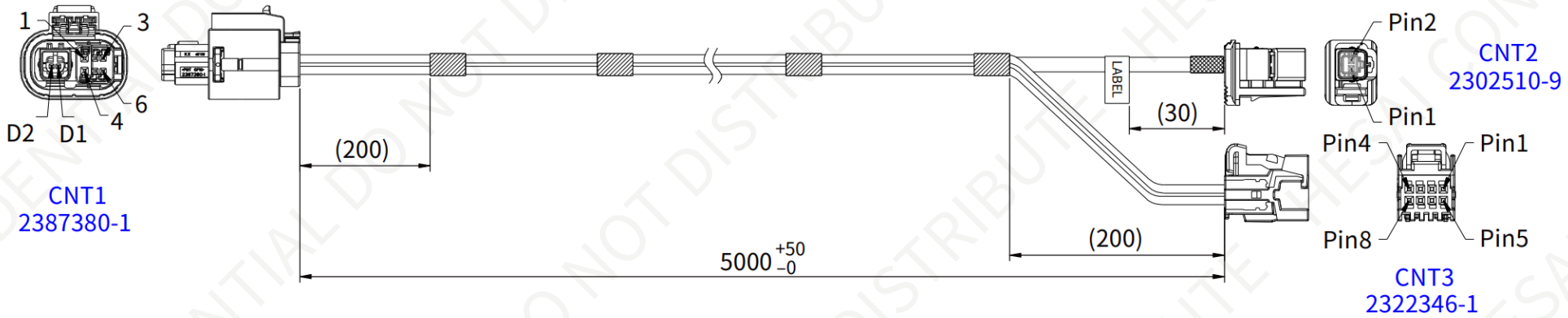


Figure 14. Cable between Lidar and Connection Box (unit: mm)

The wire colors and cross-section areas are listed below:

Pin # on CNT1 Connector	Pin # on CNT3 Connector	Signal	Wire Color	Wire Cross Section
Pin 1	Pin 4	VCC	Red	0.75 mm^2
Pin 4	Pin 8	GND	Black	0.75 mm^2

Pin # on CNT1 Connector	Pin # on CNT2 Connector	Signal	Wire Color	Wire Cross Section
D2	Pin 1	MDI-P	White	-
D1	Pin 2	MDI-N	Green	-

2.3.1. Connection box ports

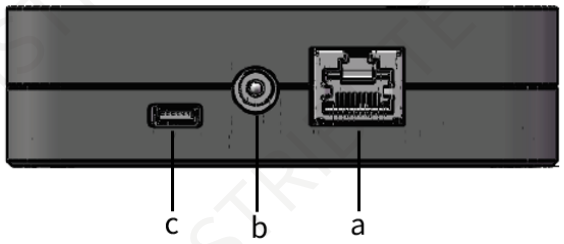


Figure 15. Connection Box (Front)

Port #	Port Name	Description
a	Standard Ethernet port	RJ45, 1000 Mbps Ethernet
b	Power port	Connects to a DC-005 DC power adapter.
c	Reserved port	Do not connect this port to external signals.

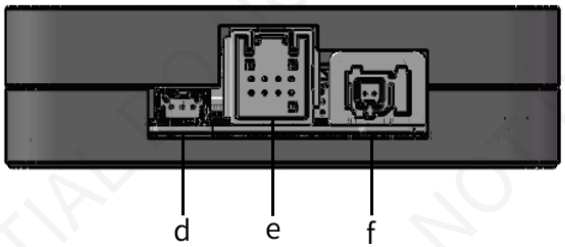


Figure 16. Connecting Box (Back)

Port #	Port Name	Description
d	Reserved port	Do not connect this port to external signals
e	Power Output port	See CNT3 connector in Figure 14. Cable between Lidar and Connection Box (unit: mm).
f	Automotive Ethernet port	See CNT2 connector in Figure 14. Cable between Lidar and Connection Box (unit: mm).

2.3.2. Connection

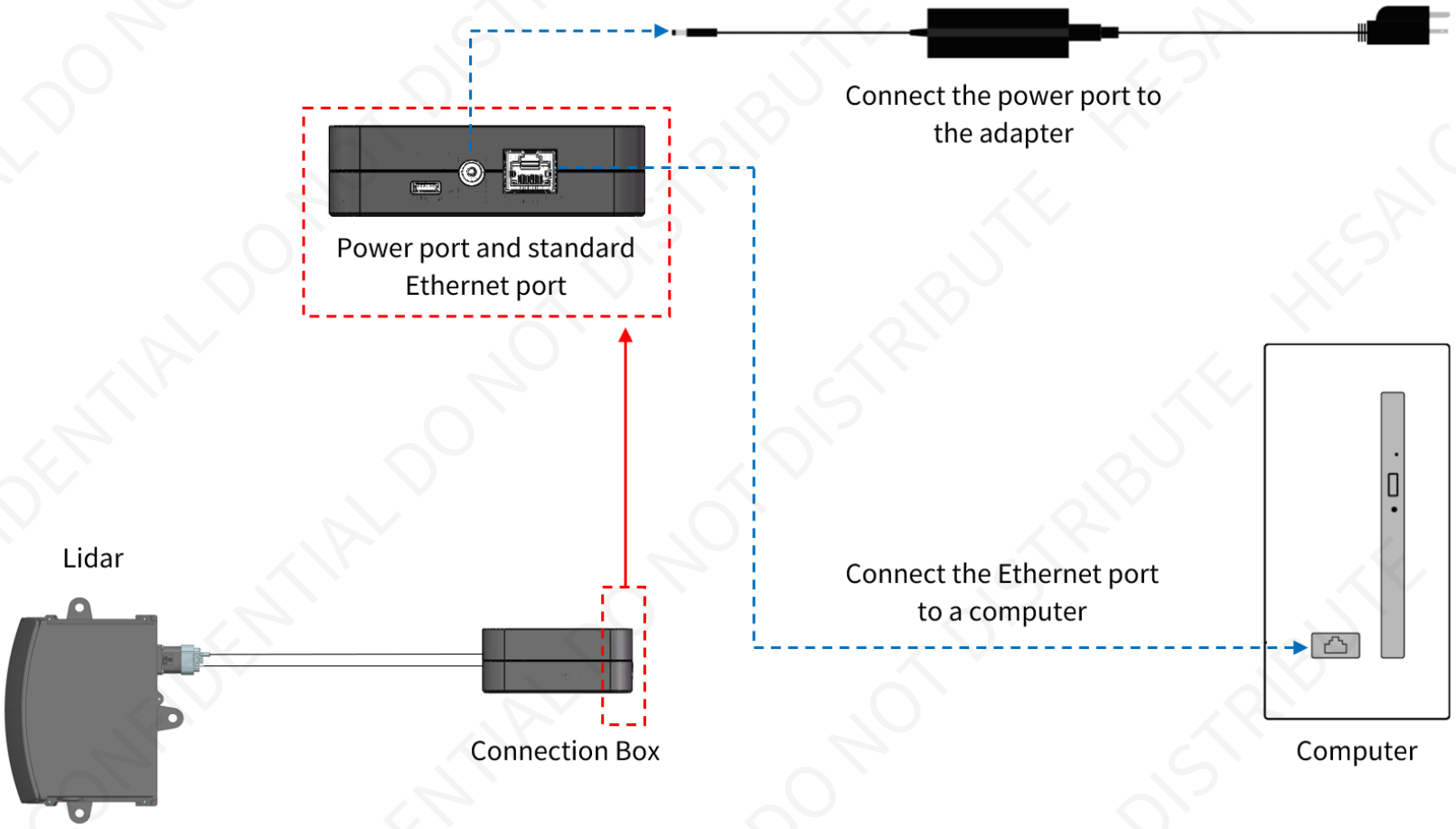


Figure 17. Connection with PTP (software simulation)

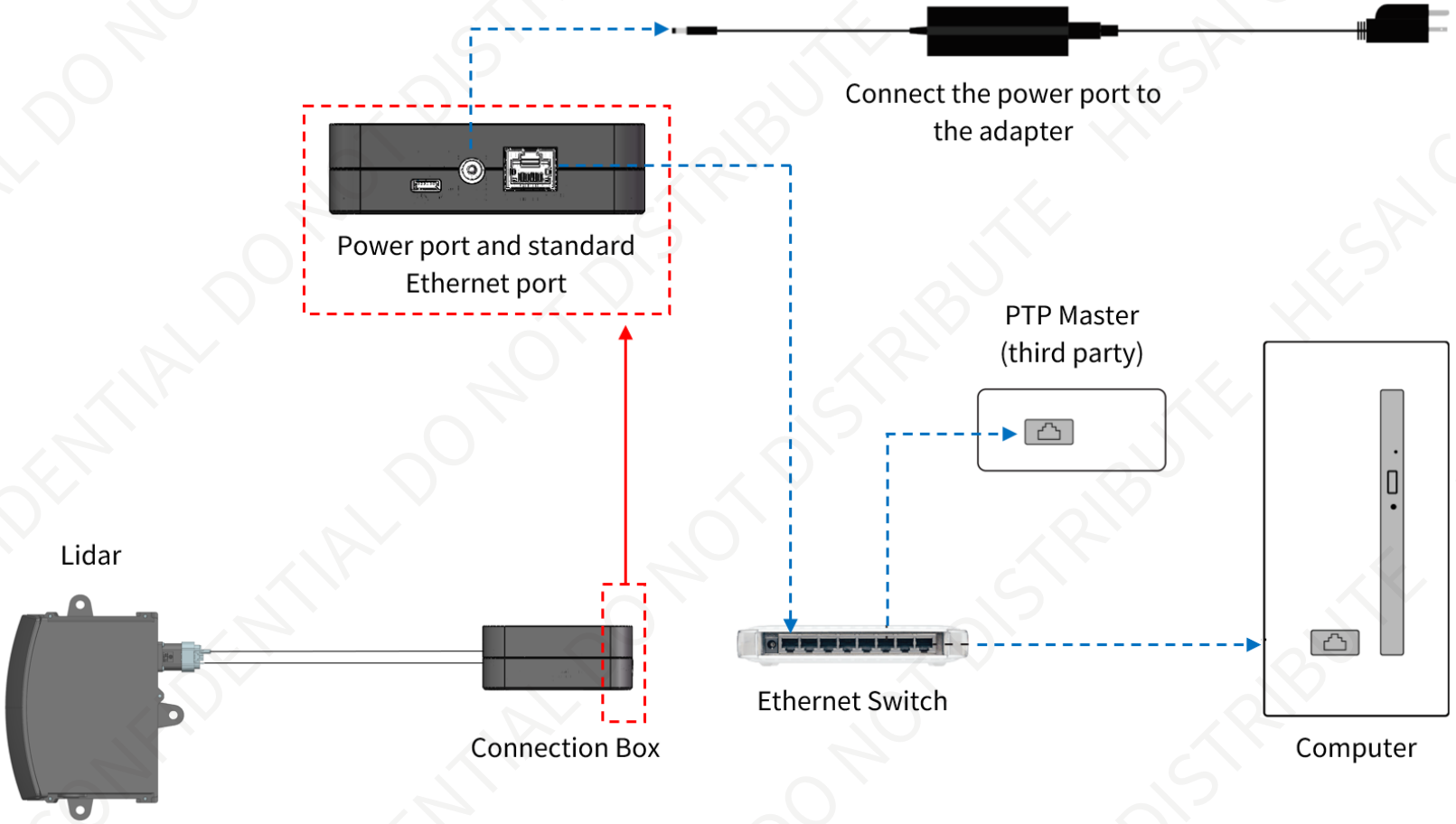


Figure 18. Connection with PTP (hardware device)

2.4. Get ready to use

Before operating the lidar, strip away the transparent protective film on the optical window.

The lidar does not have a power switch. It starts operating once connected to power and the Ethernet.

2.4.1. Network settings on the receiving host

To receive data on your PC, set the PC's IP address to 192.168.1.**X** and subnet mask to 255.255.255.0.

Range of **X**: 0 to 255 (except 201, 1 and 255)

Ubuntu	Windows
1. Open terminal. 2. Input this ifconfig command in the terminal: `~$ sudo ifconfig enp0s20f0u2 192.168.1.X` (replace `enp0s20f0u2` with the local Ethernet port name)	1. Open the Network Sharing Center and click "Ethernet". 2. In the "Ethernet Status" box, click "Properties". 3. Double-click "Internet Protocol Version 4 (TCP/IPv4)". 4. Configure the IP address to `192.168.1.X` and the subnet mask to `255.255.255.0`.

2.4.2. Tools

- To record and display point cloud data, see PandarView 2 User Manual.
- To set parameters, check device info or upgrade firmware/software, use either web control or PTC commands.
- To obtain the SDKs (Software Development Kits) for your product model, please visit Hesai's official GitHub page: https://github.com/HesaiTechnology

3. Data structure

The lidar outputs Point Cloud Data Packets.
Unless otherwise specified, all the multi-byte fields are unsigned values in little-endian format.

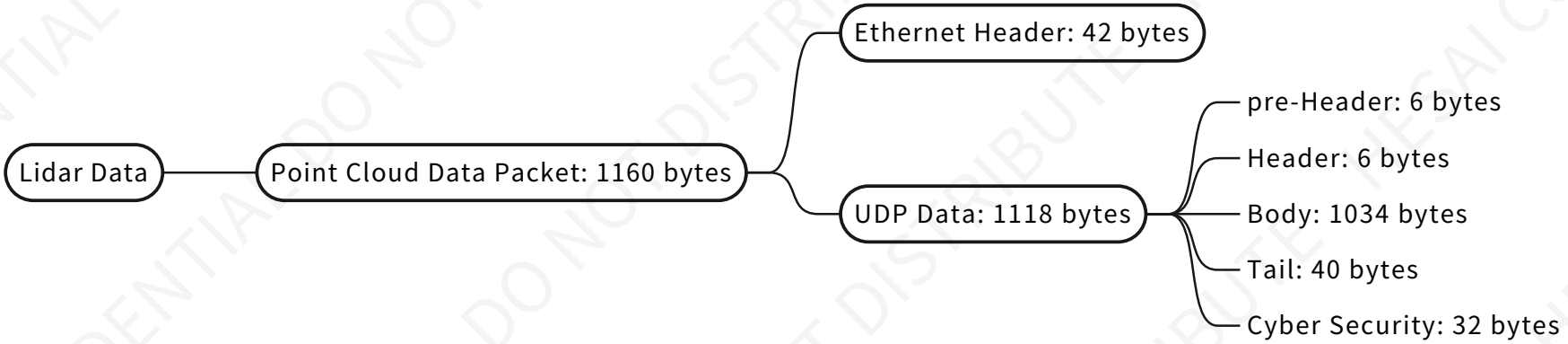


Figure 19. Data structure

3.1. Point cloud data packet

3.1.1. Ethernet header

Default IP address:

Source IP	192.168.1.201
Destination IP	255.255.255.255

Point Cloud Data Packet: Ethernet header

Field	Bytes	Description
Ethernet II MAC	12	Destination MAC: xx:xx:xx:xx:xx:xx (FF:FF:FF:FF:FF:FF for broadcast) Source MAC: xx:xx:xx:xx:xx:xx
Ethernet Data Packet Type	2	0x08, 0x00
Internet Protocol	20	Protocol parameters
UDP Port Number	4	UDP source port (0x2710, representing 10000) Destination port (0x0940, representing 2368)
UDP Length	2	8 bytes more than point cloud UDP data, see Figure 19. Data structure.
UDP Checksum	2	Checksum of the Ethernet Header

3.1.2. Point cloud UDP data

3.1.2.1. Pre-header

Field	Bytes	Description
0xEE	1	SOP
0xFF	1	SOP
Protocol Version Major	1	Main class of the point cloud UDP packet structure Current value: 0x04
Protocol Version Minor	1	Subclass of the point cloud UDP packet structure Current value: 0x03
Reserved	2	-

3.1.2.2. Header

Field	Bytes	Description
Laser Num	1	Fixed: 0x80 (128 channels)
Block Num	1	Fixed: 0x02 (2 blocks per packet)
First Block Return	1	Reserved
Dis Unit	1	Fixed: 0x04 (4 mm)
Return Num	1	Fixed: 0x02 (Each channel can generate two returns maximum.)

<table>
<tr><th>Field</th><th>Bytes</th><th>Description</th></tr>
<tr><td>Flags</td><td>1</td><td>[7:4] is reserved<table><tr><th>Bit</th><th>Value</th><th></th></tr><tr><td>[3] digital signature</td><td>1 — Yes</td><td>0 — No</td></tr><tr><td>[2] functional safety</td><td>1 — Yes</td><td>0 — No</td></tr><tr><td>[1] IMU</td><td>1 — Yes</td><td>0 — No</td></tr><tr><td>[0] UDP sequence</td><td>1 — Yes</td><td>0 — No</td></tr></table></td></tr>
</table>

3.1.2.3. Body

Field	Bytes	Description
Azimuth 1	2	For Block 1: Low-resolution part of the encoder angle Unit: 0.01° The encoder angle is measured by the optical encoder, used as the current reference angle of the azimuth.
Fine Azimuth 1	1	For Block 1: High-resolution part of the encoder angle Unit: 0.01° / 256 Encoder angle of Block 1 = `Azimuth 1` * 0.01° + `Fine Azimuth 1` * 0.01° / 256 To convert from encoder angle to point cloud horizontal angle (see Appendix A Channel distribution data).
Block 1	512	For Block 1: measurements made by each channel, starting from Channel 1 (see the table below).

Field	Bytes	Description
Azimuth 2	2	Block 2
Fine Azimuth 2	1	
Block 2	512	
CRC 1	4	CRC-32 checksum of the Body

Each block in the Body

Field	Bytes	Description
Channel X	4	Object distance = `Distance` * `Dis Unit` `Dis Unit` is specified in Section 3.1.2.2 Header.
		Reflectivity Value = Reflectivity * 1% Range: 0 to 255
		Low confidence flag, showing the confidence of the return signal. Range: 1 (low confidence), 0 (normal) Low-confidence data points can be allowed or filtered out by sending PTC commands (see Section 5 Communication protocol); allowing such points improves the detection of low-reflectivity objects.

In Dual Return mode, the measurements from each round of firing are stored in two adjacent blocks:

- The odd-numbered block is the last return, and the even-numbered block is the strongest return.
- If the last and strongest returns coincide, the second strongest return will be placed in the even-numbered block.
- The Azimuth (encoder angle) changes every two blocks.

Point Cloud Data Packet (Single Return)		Point Cloud Data Packet (Dual Return)		Point Cloud Data Packet (Dual Return)	
Block 1	Block 2	Block 1	Block 2	Block 1	Block 2
Return from this round of firing	Return from the next round of firing	Last return	Strongest return	Last and strongest return	Second strongest return

3.1.2.4. Tail

Field	Bytes	Description
Reserved	6	-
High Temperature Shutdown Flag	1	0x01 for high temperature; 0x00 for normal operation. • When a high temperature is detected, the shutdown flag will be set to 0x01, and the system will shut down after 60 s. The flag remains 0x01 during the 60 s and the shutdown period. • When the system is no longer in high temperature status, the shutdown flag will be reset to 0x00 and the system will automatically return to normal operation.
Reserved	11	-
Motor Speed	2	Spin rate of the motor Signed integer Define clockwise in the top view as positive. Unit: 0.1 RPM • By default, each of the three mirror surfaces corresponds to a point cloud frame. Thus for every motor rotation, three frames are generated. • Spin rate of the motor (RPM) = frame rate (Hz) * (60/3)

<table>
<tr><th>Field</th><th>Bytes</th><th>Description</th></tr>
<tr><td>Timestamp</td><td>4</td><td>The "µs time" part of the absolute time of this data packet
Unit: µs
Range: 0 to 999 999 µs (1 s)
To see the definition of absolute time, please refer to Appendix B Absolute time of point cloud data.</td></tr>
<tr><td>Return Mode</td><td>1</td><td>0x37 — Strongest Return Mode
0x38 — Last Return Mode
0x39 — Dual Return Mode (Last & Strongest)</td></tr>
<tr><td>Factory Information</td><td>1</td><td>Fixed: 0x42</td></tr>
<tr><td>Date & Time</td><td>1 * 6</td><td>The absolute time of this data packet, accurate to the second.
In big-endian format:<table><tr><td>Byte 1</td><td>0x00 (fixed)</td></tr><tr><td>Byte 2 to 6</td><td>Number of seconds since the Unix epoch (1970-01-01 00:00:00 UTC)</td></tr></table>To see the definition of absolute time, please refer to Appendix B Absolute time of point cloud data.</td></tr>
<tr><td>UDP Sequence</td><td>4</td><td>Sequence number of this UDP packet
0 to 0xFF FF FF FF</td></tr>
<tr><td>CRC 2</td><td>4</td><td>CRC-32 checksum of the Tail</td></tr>
</table>

3.1.2.5. Cyber security

Field	Bytes	Description
Signature	32	Point cloud signature Calculated using Point Cloud UDP Data (from Pre-Header to Tail) Algorithm: CMAC (128 bits) or HMAC-SHA256 (256 bits) This field is not yet supported.

3.1.3. Point cloud data analysis

The analysis of point cloud UDP data consists of three steps.

3.1.3.1. Analyze the vertical and horizontal angles of a data point

Take **Channel 5** in **Block 2** as an example:

1. Calculate the vertical angle (v_angle) of **Channel 5** according to Appendix C Angle correction.
   - 0° represents the horizontal direction.
   - Define upward as positive.
   - Channel # from the uppermost counts from 1.
2. Calculate the horizontal angle (h_angle_0) of **Channel 5** according to Appendix C Angle correction.
   - Define clockwise in the top view as positive.
3. For each channel, a firing time offset translates to an offset in the horizontal angle.

$$\text{h\_angle} = \text{h\_angle\_0} + \text{firing time angular offset}$$

$$\text{firing time angular offset} = \text{firing time offset of Channel 5} * \text{spin rate of the motor} * 2$$

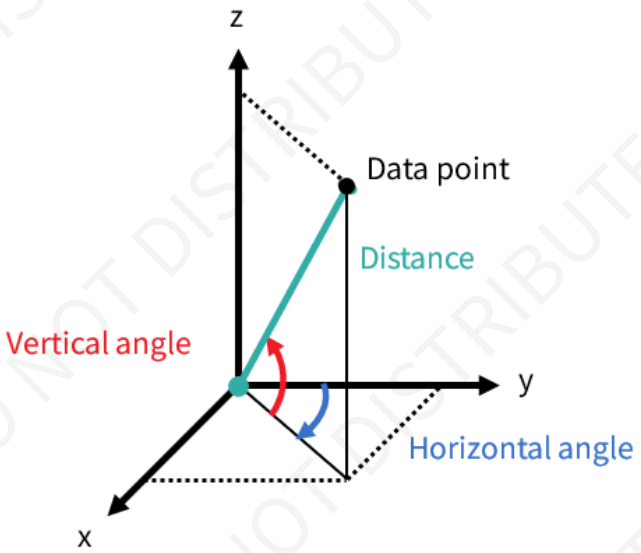
- Firing time offset: in units of s (seconds); see Section B.4 Laser firing time of each channel.
- Spin rate of the motor: in units of °/s (degrees per second); see Section 4 Web control.

3.1.3.2. Analyze the distance of a data point

Use the `Distance` field of **Block 2: Channel 5** in Section 3.1.2.3 Body.

3.1.3.3. Draw the data point in a spherical or rectangular coordinate system

In a spherical coordinate system, the vertical and horizontal angles are defined in the figure below.



3.1.3.4. Obtain the real-time point cloud data by analyzing and drawing every data point in each frame

4. Web control

Web control is used for setting parameters, checking device info, and upgrading.

To access web control,

1. Connect the lidar to your PC using an Ethernet cable.
2. Set the IP address according to Section 2.4 Get ready to use.
3. Enter this URL into your web browser: `192.168.1.201`.

- May be different for customized models. The mechanical drawings and data exclusively provided for customized models shall prevail.
- Google Chrome and Mozilla Firefox are recommended.
- Firewall port exceptions: Port 9347 (PTC/PTCS), Port 80 (HTTP), Port 443 (HTTPS), and Ports 319 and 320 (PTP 1588v2)

4.1. Home

Status	
Spin Rate	200 RPM
PTP	Free Run
Device Info	Device Log
Model	AT128E2X
S/N	ATXXXXXXXXXXXXX
MAC Address	XX:XX:XX:XX:XX:XX
Software Version	3.50.15
Firmware Version	3.10b830
RPU Version	3.50.008
Nominal Voltage	24 V
PHY Mode	Slave

<table>
<tr><th>Parameter</th><th>Description</th></tr>
<tr><td>Spin Rate</td><td>• Options: 200/400 RPM
• Detailed in the <code>Motor Speed</code> field in Section 3.1.2 Point cloud UDP data.</td></tr>
<tr><td>PTP</td><td>PTP status<table><tr><td>Free Run</td><td>No PTP master is selected.</td></tr><tr><td>Tracking</td><td>Attempting to sync with the selected PTP Master, but the absolute offset exceeds the user-specified limit in Section 4.2.3 Time settings.</td></tr><tr><td>Locked</td><td>Absolute offset is within the user-specified limit.</td></tr><tr><td>Frozen (Holdover)</td><td>Attempting to recover the connection to the PTP master.</td></tr></table></td></tr>
<tr><td>Firmware Version</td><td>Version number of FPGA</td></tr>
<tr><td>RPU Version</td><td>• Version number of RPU*
RPU (real-time processing unit) is mainly used in:
• Diagnosis for functional safety
• Loading and configuration for point cloud parameters</td></tr>
<tr><td>Nominal Voltage</td><td>• Lidar with 24 V nominal voltage: DC 9 to 32 V
• Lidar with 12 V nominal voltage: DC 9 to 16 V</td></tr>
<tr><td>PHY Mode</td><td>Communication mode for automotive Ethernet (1000Base-T1)
• Master
• Slave (by default)</td></tr>
</table>

4.2. Settings

		Reset All Settings
Control IP		
IPv4 Address		192.168.1.201
IPv4 Mask		255.255.255.0
IPv4 Gateway		192.168.1.1
VLAN		0
Settings		
Destination IP		255.255.255.255
Lidar Destination Port		2368
Fault Message Destination Port		2368
Spin Rate		200 RPM
Return Mode		Strongest
Sync Angle	✔	0
Trigger Method		Angle Based
Clock Source		PTP
Profile		1588v2
Time Offset for Lidar Lock		1
PTP Network Transport		UDP/IP
PTP Domain Number		0
PTP logAnnounceInterval		1

PTP logSyncInterval	1
PTP logMinDelayReqInterval	0
Standby Mode	In Operation
Lidar Work Mode	Standard
Lidar Fault Status	Normal
Save	

Button	Description
Reset All Settings	Reset all the configurable parameters to factory defaults, including: • Section 4.2 Settings.
Save	Save and execute all the settings on this page. Exception: Standby Mode takes effect immediately without having to click this button.

4.2.1. Network settings

<table>
<tr><th>Parameter</th><th>Options</th><th>Description</th></tr>
<tr><td>VLAN</td><td>Default: OFF
VLAN ID: 1 to 4094</td><td>To enable VLAN tagging:
Make sure the receiving host also supports VLAN.
Check the checkbox and input the lidar's VLAN ID (same as the receiving host's VLAN ID).
If the lidar's VLAN ID differs from the receiving host's, users will lose access to web control.
Once configured, the VLAN ID does not change during firmware upgrades.</td></tr>
<tr><td>Destination IP</td><td>Any address except for 0.0.0.0, 127.0.0.1, and the lidar's IP.
Default: 255.255.255.255</td><td>目的 IP<table><tr><th>Mode</th><th>Destination IP</th></tr><tr><td>Broadcast (default)</td><td>255.255.255.255</td></tr><tr><td>Multicast</td><td>User-defined</td></tr><tr><td>Unicast</td><td>Same as the PC's IP address</td></tr></table></td></tr>
<tr><td>Lidar Destination Port</td><td>Default: 2368</td><td>Destination port of Point Cloud Data Packets</td></tr>
<tr><td>Fault Message Destination Port</td><td>Default: 2368</td><td>Destination port of fault messages</td></tr>
</table>

4.2.2. Function settings

Parameter	Options	Description
Spin Rate	200/400 RPM Default: 200 RPM	The set spin rate is also shown on the Home page (see Section 4.1 Home).
Return Mode	Single Return • Last • Strongest (by default) Dual Return • Last and Strongest	Return Mode Also shown in Point Cloud Data Packets (see the `Return Mode` field in Section 3.1.2 Point cloud UDP data).
Sync Angle	30° to 150°	Phase lock angle • To activate this function, check the checkbox and input an azimuth. • At every full second, the lidar will rotate to that azimuthal position (see Section 1.2 Lidar structure). Definition of the full second: • When PTP is tracking or locked: retrieved from the PTP master clock • Otherwise: the rising edge of the lidar's internal 1 Hz signal • Detailed in Appendix B Absolute time of point cloud data. To phase-lock multiple lidars, Connect the lidars to the same clock source and set the same sync angle, and these lidars will rotate to that same azimuthal position at every full second.
Trigger Method	Angle-Based (default) Time-Based	The way laser firings are triggered. Angle-Based Lasers fire every 0.1° at 10 Hz. Time-Based Lasers fire every 41.666 us.
Standby Mode	In Operation (Default)	Standby In Standby mode, the motor stops running and lasers stop firing.

Parameter	Options	Description
Lidar Work Mode	Standard (Default) Standby Energy-Saving High-Temp-Shutdown Shutdown	-
Lidar Fault Status	Normal (Default) Fault-High-Temp-Shutdown Fault-Energy-Saving Fault-Shutdown	-

4.2.3. Time settings

Clock Source	PTP
Profile	1588v2
Time Offset for Lidar Lock	1
PTP Network Transport	UDP/IP
PTP Domain Number	0
PTP logAnnounceInterval	1
PTP logSyncInterval	1
PTP logMinDelayReqInterval	0

Parameter	Options	Description
Clock Source	fixed: PTP	External source of absolute time
Profile	1588v2 (by default) 802.1AS 802.1AS Automotive	IEEE timing and synchronization standard
Time Offset for Lidar Lock	1 to 100 µs (integer) Default: 1	Specify the upper limit of the absolute offset between Slave and Master when the lidar is in PTP Locked status; see Section 4.1 (Home)
PTP Network Transport	UDP/IP(by default) L2	Network transport protocol **UDP/IP**: Available only for 1588v2 profile **L2**: Available for all profiles
Domain Number	0 to 127 (integer) Default: 0	Domain attribute of the local clock

When using the 1588v2 profile::

Parameter	Options	Description
PTP logAnnounceInterval	-2 to 3 (Default: 1)	Time interval between Announce messages Default: 1 log second (2 seconds)
PTP logSyncInterval	-7 to 3 (Default: 1)	Time interval between Sync messages Default: 1 log second (2 seconds)
PTP logMinDelayReqInterval	-7 to 3 (Default: 0)	Minimum permitted mean time between Delay_Req messages Default: 0 log second (1 second)

4.3. Operation statistics

These operating parameters are shown in real time:

Start-up Counts	510
Internal Temperature	32.10°C
Internal Humidity	50.0% RH
Total Operation Time	559 h 43 min
Internal Temperature	**Operation Time**
< -40 °C	0 h 1 min
-40 to -20 °C	0 h 46 min
…	…
100 to 120 °C	1 h 44 min
>120 °C	0 h 0 min

4.4. Upgrade

Preparation

- Please contact Hesai technical support to receive the upgrade file.
- During the upgrade, it is recommended to place a protective cover or other opaque material over the lidar's optical window.

Upgrade

- Click the [**Upload**] button and select an upgrade file.
- When the upgrade is complete, the lidar will automatically reboot, and the past versions will be logged in the Upgrade Log.

Buttons

Upload	To upload the upgrade file
Restart	Software reboot Afterwards, the Start-Up Counts in the Operation Statistics page increments by 1; see Section 4.3 Operation statistics.

Parameter	Current Version	Description
Software Version	3.50.15	-
Firmware Version	3.10b830	Version number of FPGA
RPU Version	3.50.008	Version number of RPU (real-time processing unit) RPU is mainly used in: • Diagnosis for functional safety • Loading and configuration for point cloud parameters
Upgrade Log	-	-

The above version numbers may be different from the actual. Please refer to the web page of the lidar used.

4.5. Fault message

A freeze frame records the lidar's status information when a fault occurs and is used in diagnostic analysis.
Some of the fields are shown on this page. For more information on the complete freeze frame (527 bytes), please contact Hesai technical support.

Freeze Frame Info
freeze_frame_0: cnts: 0 event_id: 0 OCC: 0 agingcnt: 0 recover_counter: 0 operation_cycle1: 1 operation_cycle3: 1 operation_cycle4: 0 operation_cycle6: 0 status_indicator30: 0 timestamp 20: 4252631040 timestamp21: 4253089795 event_state: 3 status_data: 00000000000000002f7f0700000000004000000002f7f0700000000040000000400000000000
freeze_frame_1:

4.6. Log

The process logs on this page can be used for software troubleshooting.

Button description

Clear ALL	Clear all logs (not yet supported)
Download ALL	Download all logs

5. Communication protocol

To acquire Hesai lidar's PTC (Pandar TCP Commands) and HTTP API Reference Manual, please contact Hesai technical support.

6. Sensor maintenance

Stains on the lidar's optical window, such as dirt, fingerprints, and oil, can negatively affect point cloud data quality.

Before cleaning the optical window, please notice:

- Turn OFF the power source before cleaning.
- To avoid damaging the optical coating, do NOT apply pressure when wiping the optical window.

- Only clean the stained area of the optical window.
- Check before using a lint-free wipe or a soft sponge. If the wipe is stained, use another.

Please perform the following steps to remove the stains:

1. Thoroughly wash your hands or wear a pair of powder-free PVC gloves. Hold the metal lid and base of the lidar to avoid touching the optical window directly.
2. To remove dust, blow dry air onto the optical window, or use a piece of lint-free wipe or soft sponge to lightly brush across the dusty area. To remove persistent stains, move on to the next step.
3. Spray the optical window with warm, neutral solvent using a spray bottle.

Solvent type	Mild soap solution Maximum two tablespoons of soap in 1 quart (1 liter) of water.
Solvent temperature	20 to 25°C

4. When the stains have loosened, dip a piece of lint-free wipe or soft sponge into the solvent made in Step 3, and gently wipe the optical window back and forth along its surface.
5. Should another cleaning agent be applied to remove certain stains, repeat Steps 3 and 4.
6. Spray the optical window with clean water, and gently wipe off the remaining liquid with another piece of lint-free wipe or soft sponge.

7. Troubleshooting

If the following procedures cannot solve your problem, please contact Hesai technical support.

Symptoms	Points to check
Indicator light is off on the connection box	Make sure that the following conditions are met: • The power adapter is properly connected and in good condition; • The connection box is intact; • Input voltage and current satisfy the requirements in Section 2.3 Connection box (optional). Power on again to check if the symptom persists.
Motor is not running	Make sure that the following conditions are met: • The power adapter is properly connected and in good condition. • If a connection box is used, the connection box is intact. • Input voltage and current satisfy the requirements in Section 1.4 Specifications and Section 2.3 Connection box (optional). • web control can be accessed (see Cannot open web control); • the lidar is not in standby mode; this can be queried using either web control or PTC commands. Power on again to check if the symptom persists.

Symptoms	Points to check
Motor is running but no output data is received, neither on Wireshark nor on PandarView 2	Make sure that the following conditions are met: • Ethernet cable is properly connected (by unplugging and plugging again). • Destination IP is correctly set (using either web control or PTC commands). • Horizontal FOV is properly set (using either web control or PTC commands). • Firmware of Sensor Version is correct; this can be queried using either web control or PTC commands. • The lidar is emitting laser light; this can be checked by using an infrared camera, an infrared sensor card, or a phone camera without an infrared filter. If a connection box is used, replace the current Ethernet cable with another cable of at least Cat 6; Cat 7 or higher is recommended. Power on again to check if the symptom persists.
Can receive data on Wireshark but not on PandarView 2	Make sure that the following conditions are met: • Lidar Destination Port is correctly set (using either web control or PTC commands). • The PC's firewall is disabled, or that PandarView 2 is added to the firewall exceptions. • The latest PandarView 2 is installed on the PC (see Download page of Hesai's official website or contact Hesai technical support). Power on again to check if the symptom persists.
Cannot open web control	Make sure that the following conditions are met: • Ethernet cable is properly connected (by unplugging and plugging again). • The lidar's IP is in the same subnet with the PC's (WireShark may be used to check the lidar's IP that broadcasts data packets). Afterwards, follow the steps below: • Restart the PC, or connect the lidar to another PC; • Power on again to check if the symptom persists.

Symptoms	Points to check
Abnormal packet size (missing packets)	Make sure that the following conditions are met: • Azimuth FOV is properly set (using either web control or PTC commands); • Spin Rate is steady; this can be queried using either web control or PTC commands. • The lidar's internal temperature is between -40°C and 110°C; this can be queried using either web control or PTC commands. • Ethernet is not overloaded; • No switch is connected to the network (the data transmitted from other devices may cause network congestion and packet loss). Afterwards, follow the steps below: 1. Connect the PC only to the lidar and check for packet loss. 2. Power on again to check if the symptom persists.
Abnormal point cloud (obviously misaligned points, flashing points, or incomplete FOV)	Make sure that the following conditions are met: • The lidar's optical window is clean. If not, refer to Section 6 Sensor maintenance for the cleaning method. • The lidar's angle correction file is imported (refer to PandarView 2 User Manual). • Azimuth FOV is properly set (using either web control or PTC commands). • Spin Rate is steady; this can be queried using either web control or PTC commands. • The lidar's internal temperature is between -40°C and 110°C; this can be queried using either web control or PTC commands. Afterwards, follow the steps below: 1. Check for packet loss. 2. If no packet is missing and the point cloud flashes, please update PandarView 2 to the latest version (see Download page of Hesai's official website or contact Hesai technical support); and then restart the PC. If the point cloud is still abnormal, connect the lidar to another PC and power on again to check if the symptom persists.

Appendix A: Channel distribution data

Notes to the table

Channel No.	Counts from 1, top to bottom.
Angular position	The design values of each channel's horizontal (azimuth) angle offset and vertical (elevation) angle. • The accurate values are recorded in this lidar unit's calibration file. • Refer to Section 3.1.3 Point cloud data analysis for the data analysis scheme.
Instrument range	Actual measurement range, confined by the allocated Time of Flight (ToF) for each channel
Near- and mid-field enabled	The 32 channels with **min. instrument range** = 0.5 m are near-field-enabled channels. • All channels fire laser pulses that measure the far field (>7.2 m) • Additionally, the near-field-enabled channels also fire laser pulses that measure only the near field (0.5 to 7.2 m), at a time other than these channels' far-field firings. • The horizontal resolution of near-field measurement is always 0.2° at 10 Hz and 0.4° at 20 Hz.
Max. range @10% reflectivity	• Probability of Detection (PoD) = 50% • The values in brackets only indicate range capability, while the actual measurement range is cut off to **max. instrument range**. • Channels 97 to 128 have enhanced near- and mid-field detection, since these channels typically point to the ground in the far field.
Far-field enhanced	Channels 33 to 96 are far-field-enhanced channels, able to detect 180 m@10% (see data in **max. range @10% reflectivity**).

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
01	2.4	12.93	7.2 m	90 m	-	-	-
02	-0.65	12.73	7.2 m	90 m	-	-	-
03	2.4	12.53	0.5 m	90 m	YES	-	-
04	-0.65	12.33	7.2 m	90 m	-	-	-
05	2.4	12.13	7.2 m	90 m	-	-	-
06	-0.65	11.93	7.2 m	90 m	-	-	-
07	2.4	11.73	0.5 m	90 m	YES	-	-
08	-0.65	11.53	7.2m	90 m	-	-	-
09	2.4	11.33	7.2 m	90 m	-	-	-
10	-0.65	11.13	7.2 m	90 m	-	-	-
11	2.4	10.93	0.5 m	90 m	YES	-	-
12	-0.65	10.73	7.2 m	90 m	-	-	-
13	2.4	10.53	7.2 m	90 m	-	-	-
14	-0.65	10.33	7.2 m	90 m	-	-	-
15	2.4	10.13	0.5 m	90 m	YES	-	-
16	-0.65	9.93	7.2 m	90 m	-	-	-
17	-2.4	9.73	7.2 m	90 m	-	-	-
18	0.65	9.53	7.2 m	90 m	-	-	-
19	-2.4	9.33	0.5 m	90 m	YES	-	-
20	0.65	9.13	7.2 m	90 m	-	-	-

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
21	-2.4	8.93	7.2 m	90 m	-	-	-
22	0.65	8.73	7.2 m	90 m	-	-	-
23	-2.4	8.53	0.5 m	90 m	YES	-	-
24	0.65	8.33	7.2 m	90 m	-	-	-
25	-2.4	8.13	7.2 m	90 m	-	-	-
26	0.65	7.93	7.2 m	90 m	-	-	-
27	-2.4	7.73	0.5 m	90 m	YES	-	-
28	0.65	7.53	7.2 m	90 m	-	-	-
29	-2.4	7.33	7.2 m	90 m	-	-	-
30	0.65	7.13	7.2 m	90 m	-	-	-
31	-2.4	6.93	0.5 m	90 m	YES	-	-
32	0.65	6.73	7.2 m	90 m	-	-	-
33	2.4	6.53	7.2 m	200 m	-	180 m	YES
34	-0.65	6.33	7.2 m	200 m	-	180 m	YES
35	2.4	6.13	0.5 m	200 m	YES	180 m	YES
36	-0.65	5.93	7.2 m	200 m	-	180 m	YES
37	2.4	5.73	7.2 m	200 m	-	180 m	YES
38	-0.65	5.53	7.2 m	200 m	-	180 m	YES
39	2.4	5.33	0.5 m	200 m	YES	180 m	YES
40	-0.65	5.13	7.2 m	200 m	-	180 m	YES

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
41	2.4	4.93	7.2 m	200 m	-	180 m	YES
42	-0.65	4.73	7.2 m	200 m	-	180 m	YES
43	2.4	4.53	0.5 m	200 m	YES	180 m	YES
44	-0.65	4.33	7.2 m	200 m	-	180 m	YES
45	2.4	4.13	7.2 m	200 m	-	180 m	YES
46	-0.65	3.93	7.2 m	200 m	-	180 m	YES
47	2.4	3.73	0.5 m	200 m	YES	180 m	YES
48	-0.65	3.53	7.2 m	200 m	-	180 m	YES
49	-2.4	3.33	7.2 m	200 m	-	180 m	YES
50	0.65	3.13	7.2 m	200 m	-	180 m	YES
51	-2.4	2.93	0.5 m	200 m	YES	180 m	YES
52	0.65	2.73	7.2 m	200 m	-	180 m	YES
53	-2.4	2.53	7.2 m	200 m	-	180 m	YES
54	0.65	2.33	7.2 m	200 m	-	180 m	YES
55	-2.4	2.13	0.5 m	200 m	YES	180 m	YES
56	0.65	1.93	7.2 m	200 m	-	180 m	YES
57	-2.4	1.73	7.2 m	200 m	-	180 m	YES
58	0.65	1.53	7.2 m	200 m	-	180 m	YES
59	-2.4	1.33	0.5 m	200 m	YES	180 m	YES
60	0.65	1.13	7.2 m	200 m	-	180 m	YES

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
61	-2.4	0.93	7.2 m	200 m	-	180 m	YES
62	0.65	0.73	7.2 m	200 m	-	180 m	YES
63	-2.4	0.53	0.5 m	200 m	YES	180 m	YES
64	0.65	0.33	7.2 m	200 m	-	180 m	YES
65	2.4	0.13	7.2 m	200 m	-	180 m	YES
66	-0.65	-0.07	7.2 m	200 m	-	180 m	YES
67	2.4	-0.27	0.5 m	200 m	YES	180 m	YES
68	-0.65	-0.47	7.2 m	200 m	-	180 m	YES
69	2.4	-0.67	7.2 m	200 m	-	180 m	YES
70	-0.65	-0.87	7.2 m	200 m	-	180 m	YES
71	2.4	-1.07	0.5 m	200 m	YES	180 m	YES
72	-0.65	-1.27	7.2 m	200 m	-	180 m	YES
73	2.4	-1.47	7.2 m	200 m	-	180 m	YES
74	-0.65	-1.67	7.2 m	200 m	-	180 m	YES
75	2.4	-1.87	0.5 m	200 m	YES	180 m	YES
76	-0.65	-2.07	7.2 m	200 m	-	180 m	YES
77	2.4	-2.27	7.2 m	200 m	-	180 m	YES
78	-0.65	-2.47	7.2 m	200 m	-	180 m	YES
79	2.4	-2.67	0.5 m	200 m	YES	180 m	YES
80	-0.65	-2.87	7.2 m	200 m	-	180 m	YES

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
81	-2.4	-3.07	7.2 m	200 m	-	180 m	YES
82	0.65	-3.27	7.2 m	200 m	-	180 m	YES
83	-2.4	-3.47	0.5 m	200 m	YES	180 m	YES
84	0.65	-3.67	7.2 m	200 m	-	180 m	YES
85	-2.4	-3.87	7.2 m	200 m	-	180 m	YES
86	0.65	-4.07	7.2 m	200 m	-	180 m	YES
87	-2.4	-4.27	0.5 m	200 m	YES	180 m	YES
88	0.65	-4.47	7.2 m	200 m	-	180 m	YES
89	-2.4	-4.67	7.2 m	200 m	-	180 m	YES
90	0.65	-4.87	7.2 m	200 m	-	180 m	YES
91	-2.4	-5.07	0.5 m	200 m	YES	180 m	YES
92	0.65	-5.27	7.2 m	200 m	-	180 m	YES
93	-2.4	-5.47	7.2 m	200 m	-	180 m	YES
94	0.65	-5.67	7.2 m	200 m	-	180 m	YES
95	-2.4	-5.87	0.5 m	200 m	YES	180 m	YES
96	0.65	-6.07	7.2 m	200 m	-	180 m	YES
97	2.4	-6.27	7.2 m	90 m	-	-	-
98	-0.65	-6.47	7.2 m	90 m	-	-	-
99	2.4	-6.67	0.5 m	90 m	YES	-	-
100	-0.65	-6.87	7.2 m	90 m	-	-	-

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
101	2.4	-7.07	7.2 m	90 m	-	-	-
102	-0.65	-7.27	7.2 m	90 m	-	-	-
103	2.4	-7.47	0.5 m	90 m	YES	-	-
104	-0.65	-7.67	7.2 m	90 m	-	-	-
105	2.4	-7.87	7.2 m	90 m	-	-	-
106	-0.65	-8.07	7.2 m	90 m	-	-	-
107	2.4	-8.27	0.5 m	90 m	YES	-	-
108	-0.65	-8.47	7.2 m	90 m	-	-	-
109	2.4	-8.67	7.2 m	90 m	-	-	-
110	-0.65	-8.87	7.2 m	90 m	-	-	-
111	2.4	-9.07	0.5 m	90 m	YES	-	-
112	-0.65	-9.27	7.2 m	90 m	-	-	-
113	-2.4	-9.47	7.2 m	90 m	-	-	-
114	0.65	-9.67	7.2 m	90 m	-	-	-
115	-2.4	-9.87	0.5 m	90 m	YES	-	-
116	0.65	-10.07	7.2 m	90 m	-	-	-
117	-2.4	-10.27	7.2 m	90 m	-	-	-
118	0.65	-10.47	7.2 m	90 m	-	-	-
119	-2.4	-10.67	0.5 m	90 m	YES	-	-
120	0.65	-10.87	7.2 m	90 m	-	-	-

Channel No.	Angular position		Instrument range		Near-field enabled?	Max. range @10% reflectivity	Far-field enhanced?
	Horiz. offset	Vertical	Min	Max			
121	-2.4	-11.07	7.2 m	90 m	-	-	-
122	0.65	-11.27	7.2 m	90 m	-	-	-
123	-2.4	-11.47	0.5 m	90 m	YES	-	-
124	0.65	-11.67	7.2 m	90 m	-	-	-
125	-2.4	-11.87	7.2 m	90 m	-	-	-
126	0.65	-12.07	7.2 m	90 m	-	-	-
127	-2.4	-12.27	0.5 m	90 m	YES	-	-
128	0.65	-12.47	7.2 m	90 m	-	-	-

Appendix B: Absolute time of point cloud data

B.1. Source of absolute time

The lidar retrieves the current absolute time by connecting to an external clock source.

B.1.1. PTP as the clock source

The lidar connects to a third-party PTP master to obtain the absolute time.

- PTP can be configured using either web control or PTC commands.
- PTP signal status can be queried using either web control or PTC commands.
- No GPS Data Packets.

The absolute time is updated as follows:

PTP status	Date and time (accurate to the second)	Lidar behavior
Free run	Virtual	Since the lidar has not been locked before, it starts counting from **a virtual UTC** (such as 2000-01-01 00:00:00) using the lidar's internal 1 Hz signal.
Tracking or Locked	Synchronized	The lidar extracts the actual date and time from the PTP Master's messages.
Frozen	Drifting	When the lidar goes from Tracking/Locked to Frozen, it starts counting from **the last synchronized time** using the lidar's internal 1 Hz signal. This absolute time will gradually drift from the actual PTP time.

- PTP is a Plug & Play protocol; the lidar works as a PTP slave device and requires no additional setup.
- The `Timestamps` and `Date & Time` fields in Point Cloud Data Packets strictly follow the PTP master device. Certain PTP master devices may have a specified offset from the lidar's time output. Please verify the configuration and calibration of your PTP master device.

B.2. Absolute time of Point Cloud Data Packets

The Absolute time of Point Cloud Data Packets is $t_0 = t_s + t_{ms}$, where:

- t_s is the whole second part (see the `Date & Time` field).
- t_{ms} is the microsecond part (see the `Timestamp` field).

The definition of the above fields is in Section 3.1.2.4 Tail.

B.3. Start time of each block

Given the Absolute time of Point Cloud Data Packets as t_0, the start time of each block (i.e., the time when the first firing starts) can be calculated.

Single return mode

Block	Start time (μs)
Block 1	t_0 - 9.249 - 41.666 * 2
Block 2	t_0 - 9.249 - 41.666

Dual return mode

Block	Start time (μs)
Block 1 & Block 2	t_0 - 9.249 - 41.666

B.4. Laser firing time of each channel

Given the start time of **Block m** as T(m), m ∈ {1, 2}, the laser firing time of **Channel n in Block m** is:

$$t(m, n) = T(m) + \Delta t(n), n \in \{1, 2, \cdots, 128\}.$$

Channel No.	Δt(n)	Channel No.	Δt(n)	Channel No.	Δt(n)	Channel No.	Δt(n)
1	0	2	0	3	8240	4	4112
5	4144	6	8240	7	0	8	0
9	12424	10	4144	11	4112	12	8264
13	12376	14	12376	15	8264	16	12424
17	0	18	0	19	4112	20	8240
21	4144	22	0	23	0	24	4144
25	12424	26	8264	27	4112	28	12376
29	12376	30	12424	31	8264	32	848
33	2504	34	4976	35	6616	36	6616
37	9112	38	2504	39	848	40	10768
41	13280	42	13280	43	4976	44	9112
45	14928	46	14928	47	10768	48	2504
49	848	50	6616	51	4976	52	9112
53	6616	54	848	55	2504	56	13280
57	10768	58	4976	59	13280	60	13280
61	9112	62	10768	63	14928	64	13280
65	848	66	9112	67	13280	68	2504
69	4976	70	848	71	2504	72	14928
73	10768	74	10768	75	14928	76	4976
77	6616	78	6616	79	9112	80	10768
81	13280	82	13280	83	9112	84	4976

Channel No.	Δt(n)	Channel No.	Δt(n)	Channel No.	Δt(n)	Channel No.	Δt(n)
85	2504	86	2504	87	848	88	10768
89	14928	90	14928	91	10768	92	6616
93	4976	94	9112	95	6616	96	4112
97	12424	98	0	99	4144	100	0
101	0	102	12424	103	0	104	8264
105	4112	106	4144	107	8240	108	8240
109	8264	110	12376	111	12376	112	12424
113	4112	114	4144	115	0	116	0
117	0	118	0	119	0	120	12424
121	8264	122	8240	123	4144	124	8264
125	8240	126	12376	127	12376	128	8264

Appendix C: Angle correction

Each lidar unit corresponds to an angle correction file, which contains the corrections of horizontal angles (azimuth) and vertical angles (elevation). Such corrections are used for:

- Point cloud data analysis
- Point cloud display in PandarView 2

Angle correction file

In case you need to obtain the file again, please do one of the following:

- Send PTC command 0x05, as described in the TCP API Reference Manual (see Section 5 Communication protocol).
- Export the file using PandarView 2 according to PandarView 2 user manual.
- Contact sales representatives or technical support.

- The angle correction file is a .dat file. Please use a hex viewer/editor to check it.
- Byte size of the file: 48 + 8 * M + 368 * N

C.1. Data Format

Unless otherwise specified, all the multi-byte fields are in little-endian format.

Field	Bytes	Type	Description
0xEE	1	uint	SOP (start of packet)
0xFF	1	uint	SOP (start of packet)
Protocol Version Major	1	uint	Main class of the point cloud UDP packet structure Current value: 0x01

Field	Bytes	Type	Description
Protocol Version Minor	1	uint	Subclass of the point cloud UDP packet structure Current value: 0x05
Channel Number	1	uint	Channel number N 0x80 (128 channels)
Mirror Number	1	uint	Mirror number M 0x03 (3 mirror surfaces)
Frame Number	1	uint	Frame number F for every 360° rotation Default: 0x03 (3 frames; each mirror surface corresponds to one frame) This field is only used for PandarView 2 display configuration, not for point cloud data analysis.

Field	Bytes	Type	Description
Frame Config Byte	8	uint	Each byte (as a bitmap) corresponds to one frame, showing whether the measurements from each mirror surface are output to that frame. Only the first F frames are valid. This field is only used for PandarView 2 display configuration, not for point cloud data analysis. For example: • When F = 3 and the first 3 bytes are `0000 0001`, `0000 0010`, and `0000 0100`, the measurements from Mirror Surfaces 0/1/2 are output to Frames 0/1/2, respectively. That is, the frames are not stitched. • When F = 1 and the first byte is `0000 0111`, the measurements from Mirror Surfaces 0/1/2 are output to one frame. That is, three frames are stitched as one. The frame rate is 1/3 of that in the previous case, while the data points per frame are three times that of the previous case. • When F = 1 and the first byte is `0000 0000`, the measurements from Mirror Surfaces 0/1/2 are output to one frame according to their encoder angles in Point Cloud Data Packets. No angle correction is performed.
Resolution	1	uint	Used in the units of the fields below. Every 0x01 stands for 1°. For example: 0x01 stands for 1° and 0x02 stands for 2°.
Start_Frame [0: M-1]	4 * M	uint32 array	The encoder angle of each mirror surface's starting side Unit: Resolution / 25 600

Field	Bytes	Type	Description
End_Frame [0: M-1]	4 * M	uint32 array	The encoder angle of each mirror surface's ending side Unit: Resolution / 25 600 • The range of each mirror surface (End_Frame - Start_Frame) ≈ 120° • One mirror surface's End_Frame is exactly the next mirror surface's Start_Frame, and so on. • Sum of the three mirror surface ranges = 360°
Azimuth_Offset [0: N-1]	4 * N	int32 array	Each channel's horizontal angle offset, irrelevant to mirror rotation Unit: Resolution / 25 600
Elevation [0: N-1]	4 * N	int32 array	Each channel's vertical angle offset, irrelevant to mirror rotation Unit: Resolution / 25 600
Azimuth_Adjust [0: 23040-1]	23040 (N * 180)	int8 array	Each channel's horizontal angle adjustments for every 2° encoder angle, relevant to mirror rotation Format: 2D array [128][180] • The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯ ⋯, and 358°. • The 128 rows correspond to Channels 1 to 128. Unit: Resolution * 0.01

Field	Bytes	Type	Description
Elevation_Adjust [0: 23040-1]	23040 (N * 180)	int8 array	Each channel's vertical angle adjustments for every 2°encoder angle, relevant to mirror rotation Format: 2D array[128][180] • The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯ ⋯, and 358°. • The 128 rows correspond to Channels 1 to 128. Unit: Resolution * 0.01
SHA-256 Value	32	uint	SHA-256 hash of this angle correction file

C.2. Angle correction calculation

C.2.1. Horizontal angle of the current firing channel

$$h_{\text{angle}} = \left(\frac{\alpha}{100} + \frac{\alpha_{\text{fine}}}{25600} - \frac{\text{start\_frame}(\text{frame\_id}) \times \text{resolution}}{25600} \right) \times 2 - \frac{\alpha_{\text{offset}}(\text{channel\_id}) \times \text{resolution}}{25600} + \frac{\alpha_{\text{adjust}}(\text{channel\_id}, \text{azimuth\_id}) \times \text{resolution}}{100}$$

Encoder angle of each mirror surface's starting side (start_frame)	In the angle correction file
Each channel's horizontal angle offset (α_{offset})	In the angle correction file
Each channel's horizontal angle adjustments for every 2° encoder angle(α_{adjust})	In the angle correction file
Unit: (resolution)	In the angle correction file
Encoder angle of the current firing channel (low-resolution part α and high-resolution part α_{fine})	In the Body of Point Cloud Data Packets

C.2.2. Vertical angle of the current firing channel

$$v_{\text{angle}} = \frac{\varepsilon(\text{channel\_id}) \times \text{resolution}}{25600} + \frac{\varepsilon_{\text{adjust}}(\text{channel\_id}, \text{azimuth\_id}) \times \text{resolution}}{100}$$

Each channel's vertical angle (ε)	In the angle correction file
Each channel's vertical angle adjustments for every 2° encoder angle (ε_{adjust})	In the angle correction file

If the encoder angle (α) is not divisible by 2°, the horizontal angle adjustments (α_{adjust}) and vertical angle adjustments (ε_{adjust}) should be linearly interpolated. For example:

- If the α_{adjust} for 50° and 52° encoder angles are a and b, respectively, then at the 51° encoder angle position, α_{adjust} = (a + b) / 2.
- If the ε_{adjust} for 50° and 52° encoder angles are c and d, respectively, then at the 50.5° encoder angle position, ε_{adjust} = (3c + d) / 4.

Appendix D: Legal notice

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