HESAI

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AT128E2X

128-Channel Hybrid Solid-State Lidar User Manual

Classification: Public

Doc Version: A01-en-240310

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 do one of the following:

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

Legends and format

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

Notes: Additional information that may be helpful.

Monospace font: field names

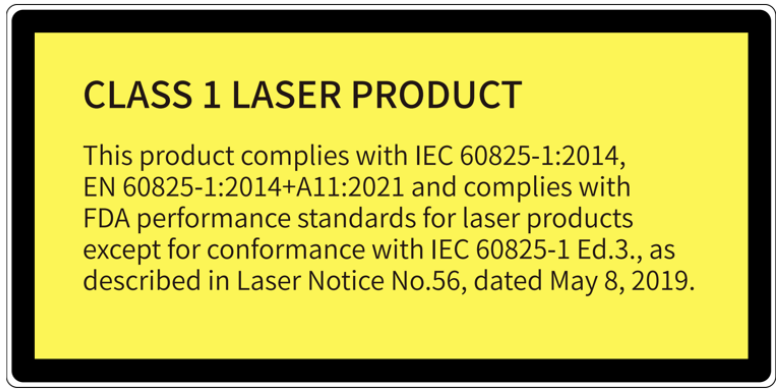
For example: `Distance` represents the Distance field.

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 access to 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, with symptoms such as significant noise or visible vibration.
- If you or people in the nearby environment feel discomfort.
- If any device or equipment in the nearby environment malfunctions.

Meanwhile, contact Hesai or an authorized Hesai service provider for more information on product disposal.

Prohibition of disassembly

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

Operating environment

Radio frequency (RF) interference

- Before using the product, make sure to read all the signs and notices on the product enclosure (including the nameplate). If specific users require not to present certification information on the nameplate, please follow the agreed-to arrangements.
- 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 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

Do NOT expose the product to corrosive liquids, including but not limited to strong acids, strong bases, esters, and ethers.

Ingress protection (IP)

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 these lidars 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

- Before powering on the product, make sure the electrical interfaces are dry and clean. Do NOT power on the product in humid conditions.
- Do NOT use out-of-spec or damaged cables or adapters.
- You are recommended to use only the cables and power adapters provided by Hesai. 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.
- Please check Section 2.2 Electrical interface 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.

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 that users do NOT 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.
- 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.

optical window

The location of the optical window is illustrated in Section 1 Introduction.

- 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 Section 6 Maintenance.
- 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.

Mounting

- 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).
- 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.

The FOV of lidar is the spatial angular range bounded by the horizontal and vertical FOV ranges (see Section 1.4 Specifications); 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 the 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, make sure to keep flammable materials away from the product's enclosure.

Certain product models support active heating of the optical window to reduce the impact of ice and frost.

- While active heating is ON, please avoid direct skin contact with the optical window.
- Users can turn off active heating.

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.

When selecting a peripheral, please refer to all relevant specifications in the product's user manual or contact Hesai technical support. Using out-of-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. 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 more product repair or maintenance issues, please contact Hesai or an authorized Hesai service provider.

Repair

Unless expressly agreed to in writing by Hesai, do NOT disassemble, repair, modify, or retrofit the product by yourself or entrust any third party to do so. 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. Basic structure

As shown in Figure 3. Mirror rotation direction (top view), a rotating mirror is used for scanning horizontally.

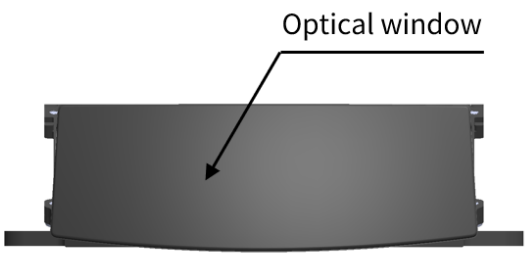


Figure 1. Front view

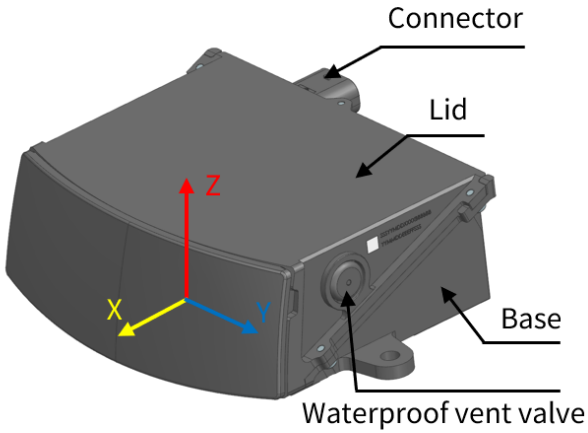


Figure 2. Coordinate system (isometric view)

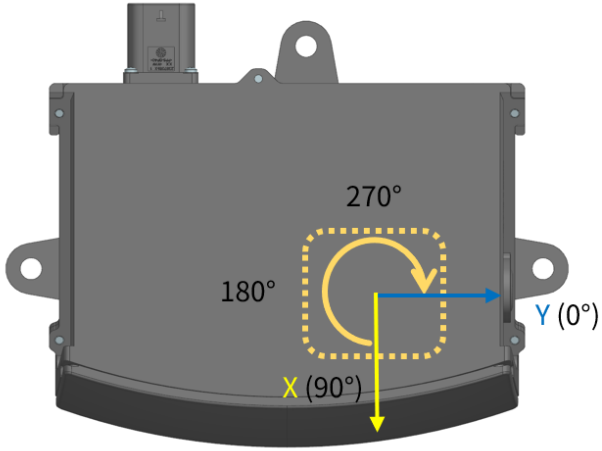


Figure 3. Mirror rotation direction (top view)

The lidar's coordinate system is illustrated in Figure 2. Coordinate system (isometric view).

- 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 rotating mirror's position and the lidar's azimuthal position (i.e., azimuth of the current firing channel) are defined in Figure 3. Mirror rotation direction (top view).

- The mirror rotates clockwise in the top view.
- 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).

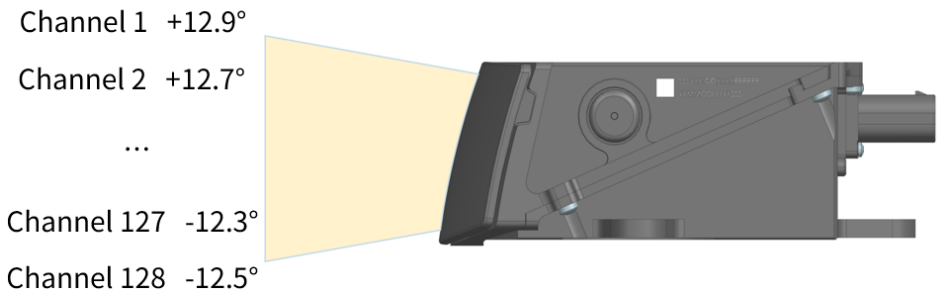


Figure 4. Channel vertical distribution

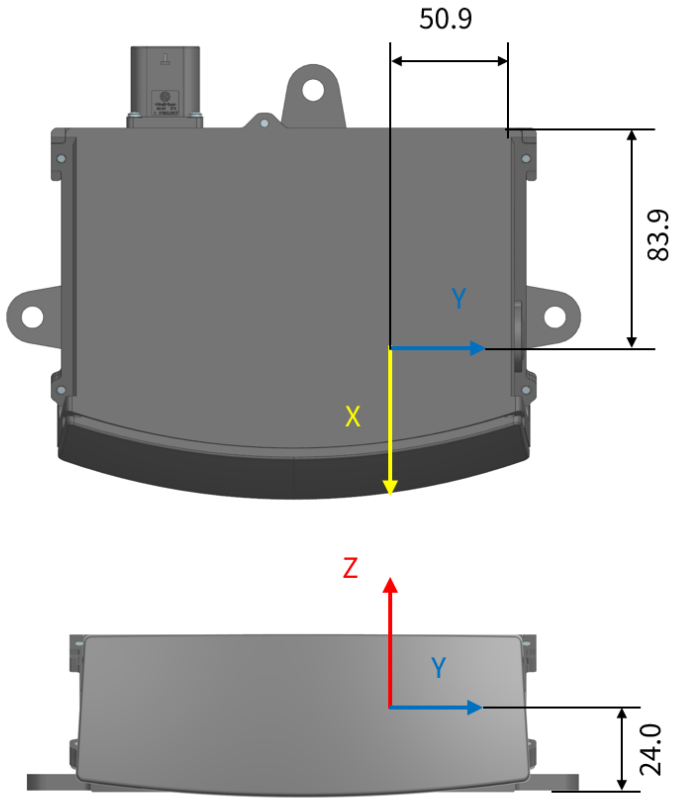


Figure 5. Origin of coordinates (unit: mm)

1.4. Specifications

SENSOR

Scanning method	1-D rotating mirror (hybrid solid-state)
Channel number	128
Ranging capability	1 to 180 m (at 10% reflectivity)
Ranging accuracy	±5 cm (typical)
Ranging precision	3 cm (1σ)
Horizontal FOV	120°
Horizontal resolution	Far-field (> 7.2 m): 0.1° (10 Hz), 0.2° (20 Hz) Near-field (0.5 to 7.2 m): 0.2° (10 Hz), 0.4° (20 Hz)
Vertical FOV	25.4° (–12.5° to 12.9°)
Vertical resolution	Far-field (> 7.2 m): 0.2° Near-field (0.5 ~ 7.2 m): 0.8°
Frame rate	10/20 Hz
Return mode	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 × 112 × 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	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: 55.9/111.8 Mbps (avg/peak) Dual Return: 111.8/223.6 Mbps (avg/peak)
Clock source	PTP (1588v2, 802.1AS, 802.1AS Automotive)
PTP clock accuracy	⩽1 µs
PTP clock drift ⑥	⩽5 µs/s

Specifications are subject to change. Please refer to the latest version of this manual.

Notes to 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**	• Defined as the point cloud data points (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 (1164 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 × 1164 bytes ◦ With unit conversion, point cloud average data rate = 6000 × 1164 × 8 × 1E–6 ≈ 55.9 Mbps. • In **Dual Return Mode**, the 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

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

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

2.1. Mechanical installation

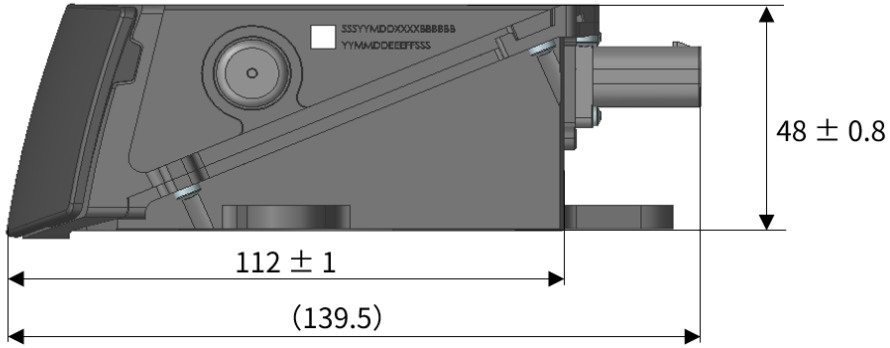


Figure 6. Right side view (unit: mm)

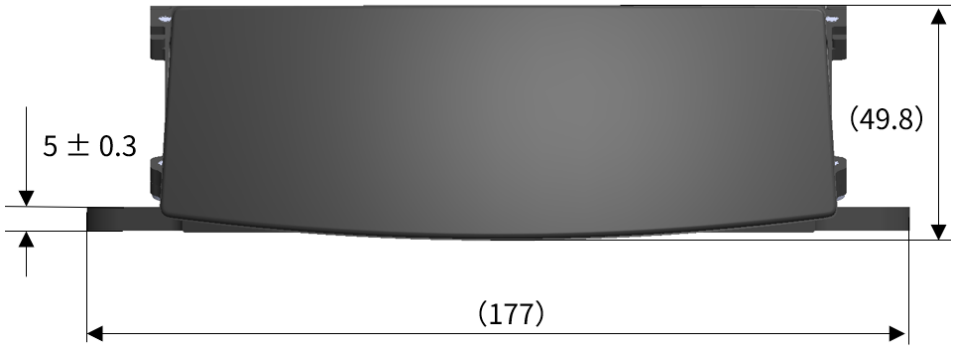


Figure 7. Front view (unit: mm)

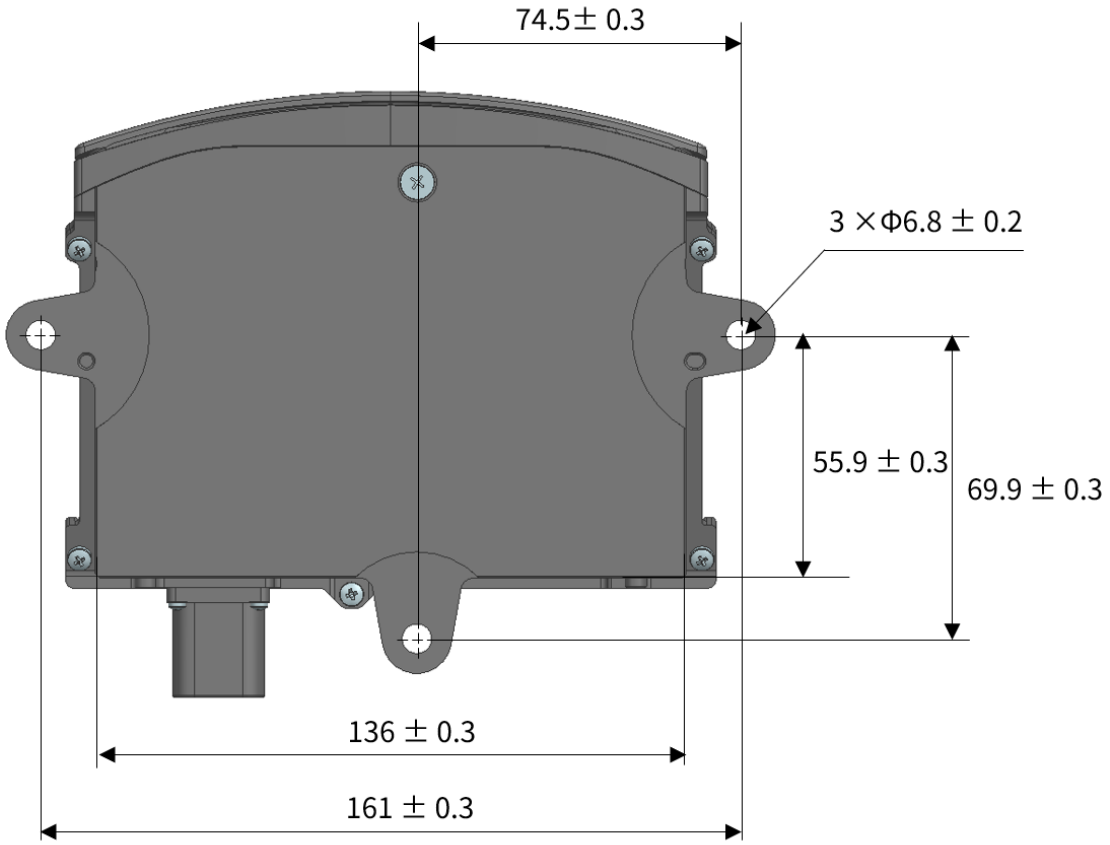


Figure 8. Bottom view (unit: mm)

2.2. Electrical interface

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

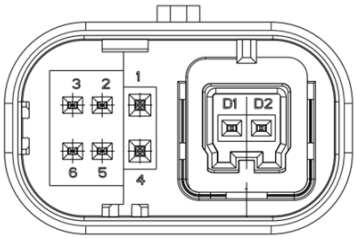


Figure 9. TE connector (male socket): dimensions and pins

2.2.1. Pin description

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

Please avoid touching the reserved pins with bare hands.

2.2.2. Connector use

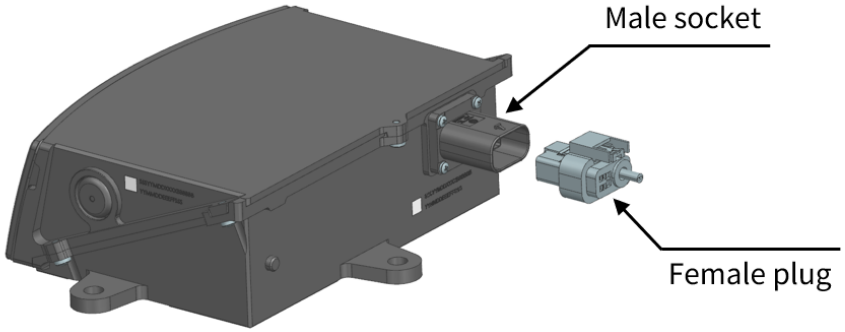


Figure 10. Connectors

- Before connection, check the pins on the socket and the holes on the plug. In case of bent pins or damaged holes, stop using the connector and contact technical support.
- To prevent breakdowns, turn off the power source before connection and disconnection.
- 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.
- For further troubleshooting, please contact Hesai's technical support or obtain work instructions from the connector manufacturer.
- The connector is designed to withstand at least 20 mating cycles; exceeding this number may increase the risk of connector damage.

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 until a click is heard. 3. Push down the black clip and pull the plug from the socket.

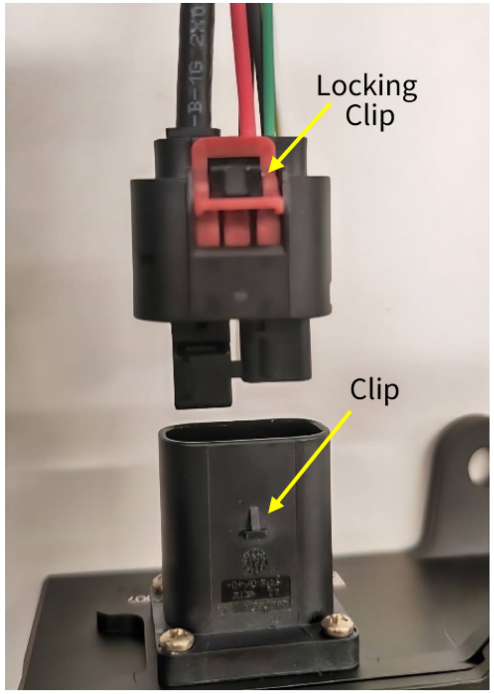


Figure 11. Connection

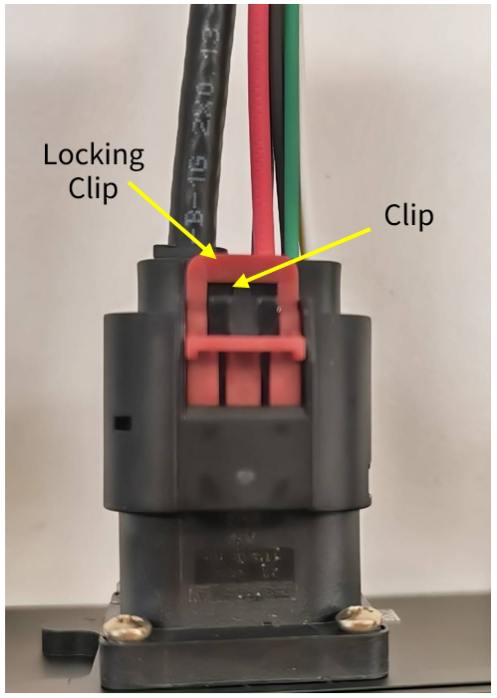


Figure 12. Disconnection

2.2.3. Cables (Ethernet)

Outside diameter (OD) = 4.10 ± 0.20 mm

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

2.3. Connection box (optional)

Users may connect the lidar with or without a connection box.

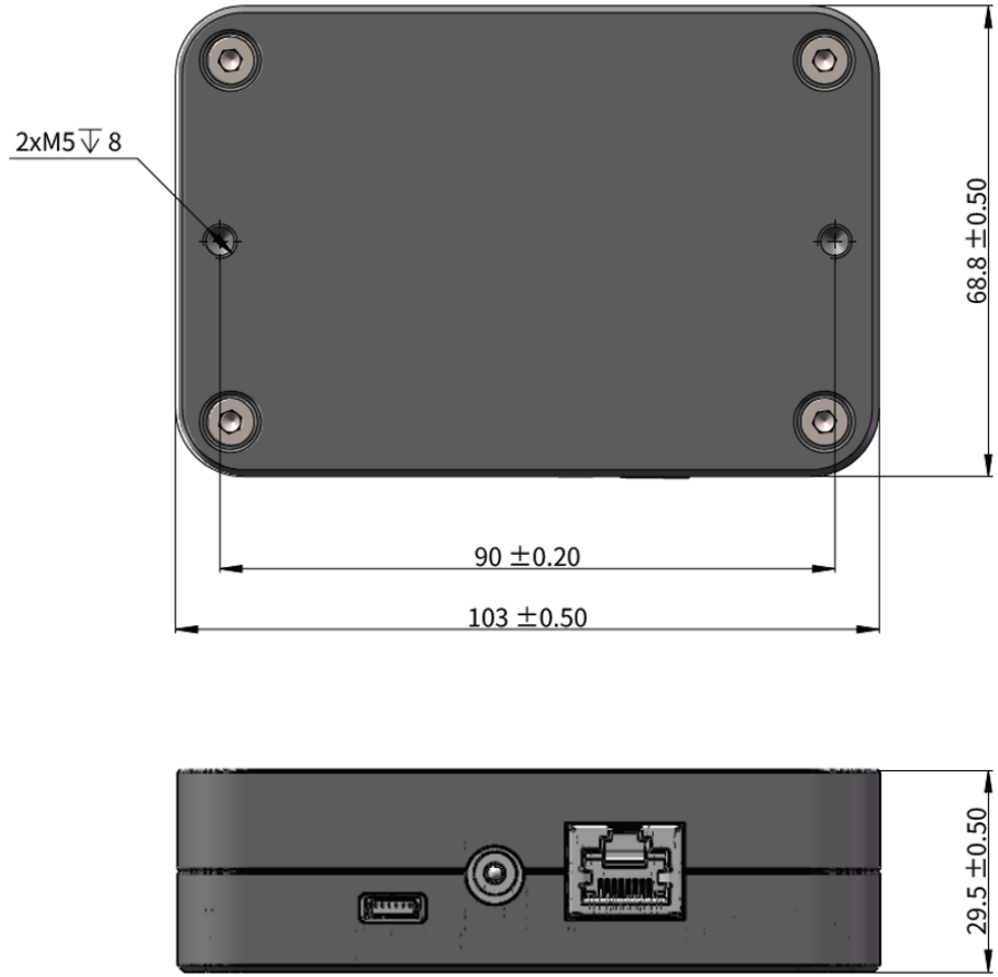


Figure 13. Connection box (unit: mm)

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.

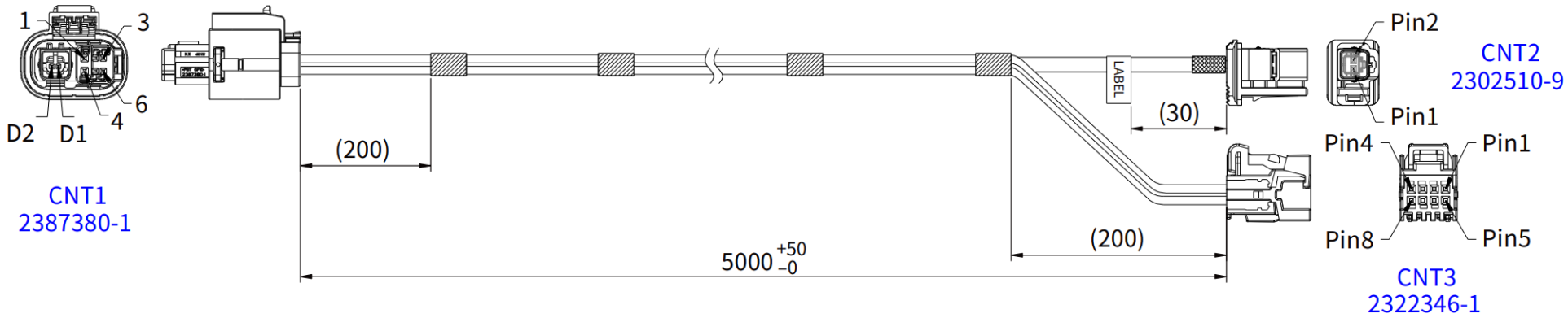


Figure 14. Cable between lidar and connection box (unit: mm)

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

Pin No. on CNT1 connector	Pin No. 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 No. on CNT1 connector	Pin No. on CNT 2	Signal	Wire color	Wire cross section
D2	Pin 1	MDI-P	White	-
D1	Pin 2	MDI-N	Green	-

2.3.1. Ports

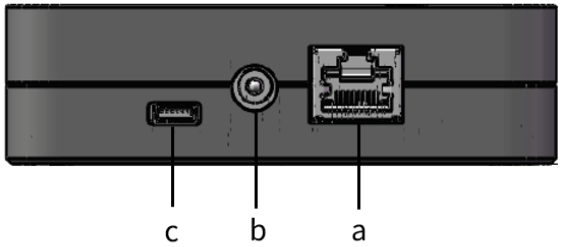


Figure 15. Connection box (front)

Port No.	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.

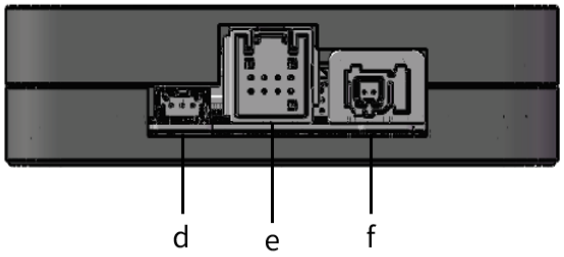


Figure 16. Connection box (back)

Port No.	Port name	Description
d	Reserved port	Do not connect this port to external signals.

Port No.	Port name	Description
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

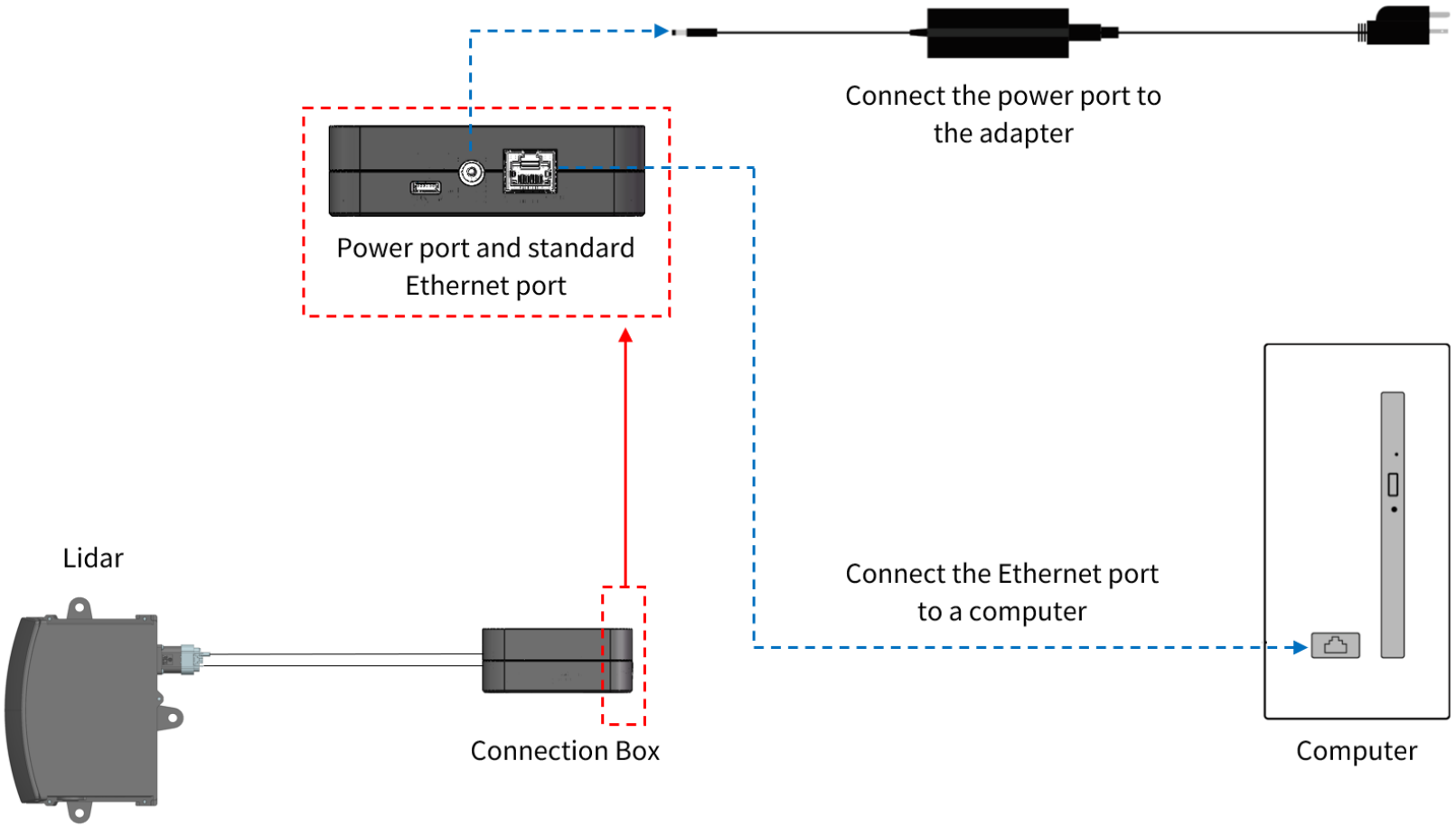


Figure 17. Connection with PTP (software simulation)

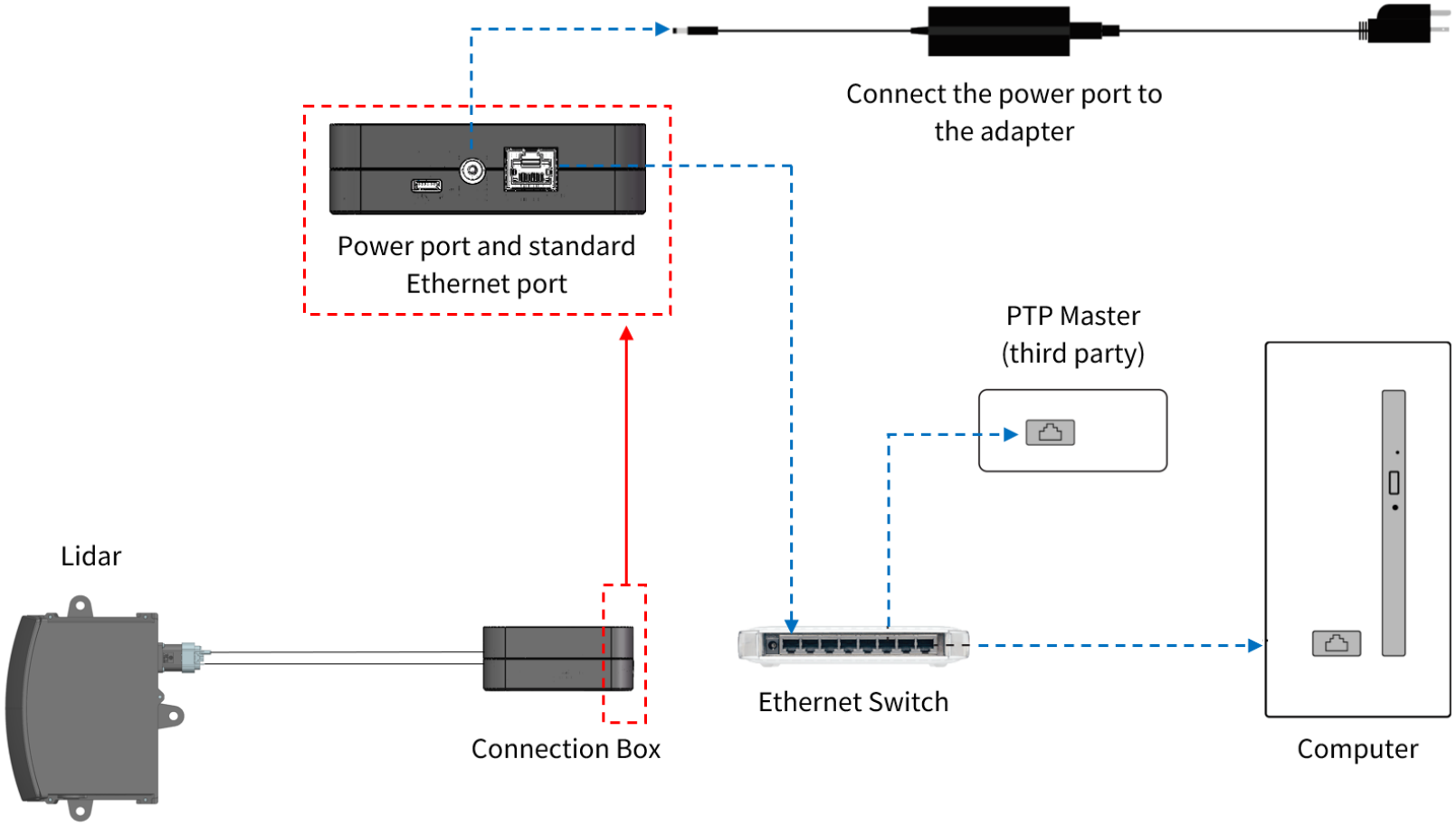


Figure 18. Connection with PTP (hardware device)

2.4. Network settings on the receiving host

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

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 the 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. Go to the "Control Panel". 2. Click "Network and Internet" > "Network and Sharing Center" > "Change adapter settings". 3. Right-click the "Ethernet" interface and select "Properties". 4. Double-click "Internet Protocol Version 4 (TCP/IPv4)". 5. Select "Use the following IP addresses" > Configure the IP address to 192.168.1.**X** and the subnet mask to 255.255.255.0.

2.5. Tools

Tool	Purpose	Where to find it
PandarView 2 (point cloud visualization software)	To record and display point cloud data.	Visit the Download page of Hesai's official website or contact Hesai technical support.
web control、API	To set parameters, check device info or upgrade firmware/software Network parameters: • Default Source IPv4 address: 192.168.1.201 • Default PTC port: 9347	• web control: See Section 4 Web control. • API: Please contact Hesai technical support.

Tool	Purpose	Where to find it
software development kits (SDKs) and ROS drivers	To assist development	Visit Hesai's official GitHub page: https://github.com/HesaiTechnology

3. Data structure

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

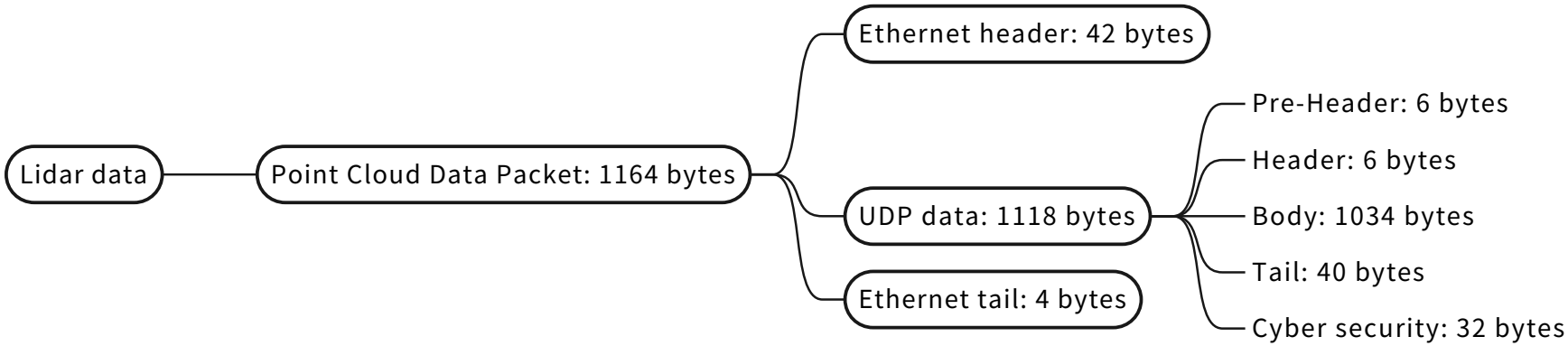


Figure 19. Data structure

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	Byte(s)	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	Source port (0x2710, representing 10000) Destination port (0x0940, representing 2368)
UDP Length	2	Eight 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	Byte(s)	Description
0xEE	1	Start of Packet
0xFF	1	Start of Packet
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	Byte(s)	Description
Channel Num	1	0x80 (128 channels)
Block Num	1	0x02 (2 blocks per packet)
First Block Return	1	Reserved
Dis Unit	1	0x04 (4 mm)
Return Num	1	0x02 (Each channel can generate two returns maximum.)

<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Flags</td><td>1</td><td>[7:4] is reserved
[3:0] indicates whether this data packet contains the following information (0b1001 by default):
<table>
<tr><th>Bit</th><th colspan="2">Value</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

Return mode

See the **`Return Mode`** field in Section 3.1.2.4 Tail.

In Single Return mode, the measurements of each round of firing are stored in one block.

In Dual Return mode, the measurements of each round of firing are stored in two adjacent blocks, and the **`Azimuth`** fields of these two blocks are the same.

Return Mode	Odd-numbered block	Even-numbered block	Note
Last and Strongest	Last return	Strongest return	If the last return is also the strongest, then the even-numbered block stores the second strongest return.

Field	Byte(s)	Description
Azimuth 1	2	For Block 1: Low-resolution part of the encoder angle Unit: 0.01° • Encoder angle is measured by the optical encoder and is used as the current reference azimuth of this block. • To convert from encoder angle to point cloud horizontal angle, see Section C.2 Angle correction calculation.
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
Block 1	512	For Block 1: Measurements made by each channel (starting from Channel 1) (see the table below).
Azimuth 2	2	See above.
Fine Azimuth 2	1	
Block 2	512	
CRC 1	4	CRC-32 checksum of the Body

Each block in the Body

<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Channel 1</td><td>4</td><td>Measurements of Channel 1
<table>
<tr><th>Field</th><th>Bytes</th><th>Description</th></tr>
<tr><td>Distance</td><td>2</td><td>Object distance = Distance × Dis Unit
Dis Unit is specified in Section 3.1.2.2 Header.</td></tr>
<tr><td>Reflectivity</td><td>1</td><td>Reflectivity Value = Reflectivity × 1%
Range: 0 to 255</td></tr>
<tr><td>Confidence</td><td>1</td><td>Low confidence flag, showing the confidence of the return signal.
Value: 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.</td></tr>
</table></td></tr>
<tr><td>…</td><td>…</td><td>…</td></tr>
<tr><td>Channel 128</td><td>4</td><td>Measurements of Channel 128</td></tr>
</table>

3.1.2.4. Tail

Field	Byte(s)	Description
Reserved	6	-
High Temperature Shutdown Flag	1	0x01 for high temperature; 0x00 for normal operation. • When 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
Timestamp	4	The "µs time" part of the absolute time of this data packet Unit: µs Range: 0 to 999 999 µs To see the definition of absolute time, please refer to Appendix B Absolute time of point cloud data.
Return Mode	1	0x37 — Strongest Return Mode 0x38 — Last Return Mode 0x39 — Dual Return Mode (Last and Strongest)

<table>
<tr><th>Field</th><th>Byte(s)</th><th>Description</th></tr>
<tr><td>Factory Information</td><td>1</td><td>0x42</td></tr>
<tr><td>Date & Time</td><td>1 × 6</td><td>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	Byte(s)	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. Ethernet tail

Field	Byte(s)	Description
FCS	4	Frame check sequence

3.1.4. Point cloud data analysis method

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

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

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

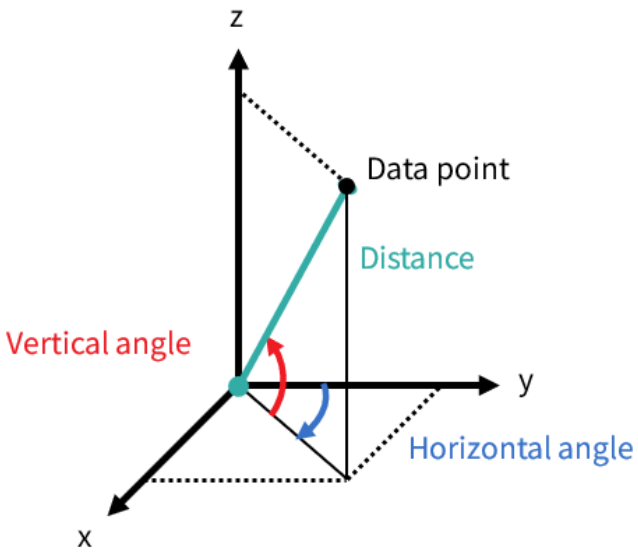
1. Calculate the vertical angle (v_angle) of **Channel 5** according to Appendix C Angle correction.
   - 0° represents the horizontal direction.
   - The upward direction is defined as positive.
   - Channel number counts from 1, top to bottom.
2. Calculate the horizontal angle (h_angle) of **Channel 5** according to Appendix C Angle correction.
   - The 0° position is defined in Figure 3. Mirror rotation direction (top view).

3.1.4.2. Analyze the distance of a data point

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

3.1.4.3. 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.



3.1.4.4. 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. Complete Section 2.4 Network settings on the receiving host.
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 Motor Speed 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 sync.</td></tr>
<tr><td>Locked</td><td>The absolute offset is within the user-specified limit.</td></tr>
<tr><td>Frozen (Holdover)</td><td>The lidar has lost connection to the PTP master and is attempting to recover it. Meanwhile, lidar time will drift from the last synchronized time. When the time drift exceeds the specification, PTP status will change to Free Run.</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 (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 **[Save]**.

4.2.1. Network

<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 except 0.0.0.0, 127.0.0.1, and the lidar's IPv4 address

Default: 255.255.255.255</td><td><table><tr><th>Communication 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 IPv4 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

Parameter	Options	Description
Spin Rate	200/400 RPM Default: 200 RPM	Spin rate of the motor The accurate spin rate is shown in Point Cloud Data Packets (see the **`Motor Speed`** field in Section 3.1.2.4 Tail). The set spin rate is also shown on the Home page (see Section 4.1 Home).
Return Mode	Single Return • Last • Strongest (default) Dual Return • Last and Strongest	Return Mode Also shown in Point Cloud Data Packets (see the **`Return Mode`** field in Section 3.1.2.4 Tail).

Parameter	Options	Description
Sync Angle	30° to 150° Unit: °	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. Lidar azimuthal position is defined in Section 1.2 Basic structure. Definition of the full second (detailed in Section B.1 Source of absolute time): • When PTP is tracking or locked, the full second is retrieved from the PTP master clock. • When PTP is frozen or in free run, the full second is defined as the rising edge of the lidar's internal 1 Hz signal. To phase-lock multiple lidar units, connect them to the same clock source and set the same sync angle. These lidar units will rotate to the 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.
Lidar Work Mode	Standard (Default) Standby Energy-Saving High-Temp-Shutdown Shutdown	-

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

4.2.3. Time sync

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 (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(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, these additional parameters can be configured:

Parameter	Options	Description
PTP logAnnounceInterval	–2 to 3 (Default: 1)	Time interval between Announce messages Default: 1 (2^1 = 2 seconds)
PTP logSyncInterval	–7 to 3 (Default: 1)	Time interval between Sync messages Default: 1 (2^1 = 2 seconds)
PTP logMinDelayReqInterval	–7 to 3 (Default: 0)	Minimum permitted mean time between Delay_Req messages Default: 0 (2^0 = 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
–20 to 0°C	0 h 49 min
0 to 20°C	8 h 40 min
20 to 40°C	38 h 20 min
40 to 60°C	393 h 17 min
60 to 80°C	109 h 50 min
80 to 100°C	6 h 16 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: 00000000000000002f7f0700000000040000000002f7f07000000000400000004000000000
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

HTTP API and **Pandar TCP Commands (PTC) API** can be used to communicate with Hesai lidars.

To acquire the API reference manuals, please contact Hesai technical support.

Pandar TCP Commands (PTC) API can be used to communicate with Hesai lidars.

To acquire the API reference manuals, please contact Hesai technical support.

6. Maintenance

Stains on lidar's optical window, such as dirt, fingerprints, and oil will negatively affect point cloud data quality. Please clean the optical window in time.

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

Only the stained area of the optical window needs to be cleaned.

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 clean piece of lint-free wipe or soft sponge to lightly brush across the dusty area. If persistent stains exist, perform the following steps; otherwise the cleaning is done.
3. Add warm, neutral solvent into a spray bottle and spray the optical window.

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. • The 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. • The 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 confirmed using either web control or PTC commands. If a connection box is used, the connection box is intact. Power on again to check if the symptom persists.

Symptoms	Points to check
Motor is running but no output data is received, neither by Wireshark nor by 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; this can be confirmed using either web control or PTC commands. • Azimuth FOV is properly set; this can be confirmed using either web control or PTC commands. • Firmware of Sensor Version is correct; this can be confirmed using either web control or PTC commands. • The lidar is emitting laser light; this can be confirmed 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.
Output data can be received by Wireshark but not by PandarView 2.	Make sure that the following conditions are met: • Lidar Destination Port is correctly set, this can be confirmed using either web control or PTC commands. • The PC's firewall is disabled, or PandarView 2 is added to the firewall exceptions. • The latest PandarView 2 is installed on the PC (see Downloads page of Hesai's official website or contact Hesai technical support). Power on again to check if the symptom persists.
Web control cannot be accessed.	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). Restart the PC, or connect the lidar to another PC. Power on the lidar again to check if the symptom persists.

Symptoms	Points to check
The number of data packets received is abnormal, indicating missing packets.	Make sure that the following conditions are met: • Azimuth FOV is properly set; this can be confirmed using either web control or PTC commands. • Spin Rate is steady; this can be confirmed using PandarView 2, web control, or PTC commands. • The lidar's internal temperature is between –40°C and 110°C; this can be confirmed using PandarView 2, 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). Connect the PC to no other devices but the lidar and check for packet loss. Power on the lidar again to check if the symptom persists.
The point cloud is abnormal, showing 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 Maintenance for the cleaning method. • The lidar's angle correction file is imported (refer to PandarView 2 User Manual). • Azimuth FOV is properly set; this can be confirmed using either web control or PTC commands. • Spin Rate is steady; this can be confirmed using PandarView 2, web control, or PTC commands. • The lidar's internal temperature is between –40°C and 110°C; this can be confirmed using PandarView 2, 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 Downloads page of Hesai's official website or contact Hesai technical support); and then restart the PC. If the point cloud is still abnormal: 1. Connect the lidar to another PC and another network. 2. Power on again and check if the symptom persists.

Appendix A: Channel distribution data

Notes to the table

Channel number	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 angle correction file. • To analyze point cloud data, refer to Section 3.1.4 Point cloud data analysis method.
Instrumented range	Actual measurement range, confined by the allocated Time of Flight (ToF) for each channel
Near-field enabled	The 32 channels with **min. instrumented range** = 0.5 m are **near-field-enabled channels**. • All the 128 channels fire laser pulses that detect the far field (> 7.2 m). Additionally, the 32 **near-field-enabled channels** also fire laser pulses that only detect the near field (0.5 to 7.2 m). • The horizontal resolution of near-field measurement is always 0.2° at 10 Hz and 0.4° at 20 Hz.
Max. range @10% reflectivity	Channels 97 to 128 only provide near- and mid-field detection, since these channels typically point to the ground.
Far-field	Channels 33 to 96 are far-field channels, able to detect 210 m @10% reflectivity (see data in the **max. range @10% reflectivity** column).

Channel No.	Angular position		Instrumented range		Near-field enabled?	Max. range @10% reflectivity	Far-field?
	Horiz. offset	Vertical	Min	Max			
1	2.4°	12.93°	7.2 m	90 m	-	-	-
2	–0.65°	12.73°	7.2 m	90 m	-	-	-
3	2.4°	12.53°	0.5 m	90 m	YES	-	-
4	–0.65°	12.33°	7.2 m	90 m	-	-	-
5	2.4°	12.13°	7.2 m	90 m	-	-	-
6	–0.65°	11.93°	7.2 m	90 m	-	-	-
7	2.4°	11.73°	0.5 m	90 m	YES	-	-
8	–0.65°	11.53°	7.2m	90 m	-	-	-
9	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	-	-	-

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
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
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
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	-	-	-
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	-	-	-
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 absolute time is updated as follows:

PTP status	Date and time (accurate to the microsecond)	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	$t_0 - 9.249 - 41.666 \times 2$
Block 2	$t_0 - 9.249 - 41.666$

Dual return mode

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

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 this 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	Byte(s)	Type	Description
0xEE	1	uint	Start of Packet
0xFF	1	uint	Start of Packet
Protocol Version Major	1	uint	Main class of the angle correction data structure Current value: 0x01

Field	Byte(s)	Type	Description
Protocol Version Minor	1	uint	Subclass of the angle correction data structure Current value: 0x05
Channel Number	1	uint	Channel number N Always 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.
Frame Config Byte	8	uint	The first F bytes represent the configuration of F frames, with one byte per frame; the other bytes are not used. Each byte is a bitmap: The first M bits correspond to M mirror surfaces; the other bits are not used. If a bit is set to 1, the measurements from the corresponding mirror surface are output to the byte's corresponding frame; otherwise, the measurements from that mirror surface is not output. See Examples of the Frame Config Byte. This field is only used for PandarView 2 display configuration, not for point cloud data analysis.

Field	Byte(s)	Type	Description
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/25600
End_Frame [0: M-1]	4 × M	uint32 array	The encoder angle of each mirror surface's ending side Unit: Resolution/25600 • The range of each mirror surface (**`End_Frame`** – **`Start_Frame`**) * Resolution / 25600 ≈ 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/25600
Elevation [0: N-1]	4 × N	int32 array	Each channel's vertical angle offset, irrelevant to mirror rotation Unit: Resolution/25600
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 128 rows correspond to Channels 1 to 128. • The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯ ⋯, and 358°. Unit: Resolution × 0.01

Field	Byte(s)	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 128 rows correspond to Channels 1 to 128. • The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ⋯ ⋯, and 358°. Unit: Resolution × 0.01
SHA-256 Value	32	uint	SHA-256 hash of this angle correction file

Examples of the Frame Config Byte

Frame number F	First F bytes of `Frame Config Byte`	Description
F = 3	0000 0001, 0000 0010, 0000 0100	• The measurements from Mirror Surfaces 0/1/2 are output to Frames 0/1/2, respectively. • The frames are not stitched.
F = 1	0000 0111	• The measurements from Mirror Surfaces 0/1/2 are output to one frame. • Every 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.
F = 1	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.

C.2. Angle correction calculation

C.2.1. Horizontal angle of the current firing channel

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

Encoder angle of each mirror surface's starting side (start_frame)	See angle correction file.
Each channel's horizontal angle offset (α_{offset})	See angle correction file.
Each channel's horizontal angle adjustments for every 2° encoder angle (α_{adjust})	See angle correction file.
Unit: (resolution)	See angle correction file.
Encoder angle of the current firing channel (low-resolution part α and high-resolution part α_{fine})	See **`Azimuth 1`** and **`Fine Azimuth 1`** in the Section 3.1.2.3 Body.

C.2.2. Vertical angle of the current firing channel

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

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