



# AT128E2X

128-Channel  
Hybrid Solid-State Lidar  
User Manual



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# 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:

- Visit the Download page of Hesai's official website: <https://www.hesaitech.com/downloads/>
- Or contact your sales representative at Hesai
- Or contact Hesai's technical support team: [service@hesaitech.com](mailto:service@hesaitech.com)

## ■ Technical Support

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

[service@hesaitech.com](mailto: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.

# 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

#### **CLASS 1 LASER PRODUCT**

This product complies with IEC 60825-1: 2014, EN 60825-1: 2014 + A11: 2021 and complies with FDA performance standards for laser products except for conformance with IEC 60825-1 Ed.3., as described in Laser Notice No.56, dated May 8, 2019.

## Hot Surface



### Hot parts!

Burned fingers when handling the parts.

Wait one-half hour after switching off before handling parts.

## Abnormalities

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

- You suspect that the product malfunctions or is damaged. For example, the product produces significant noise or is visibly vibrating.
- You or other people in the nearby environment feel discomfort.
- 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

- 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.
- 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 may exist in the product's operating environment, please contact Hesai's technical support team to obtain the shock and vibration limits of this 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 high concentrations of flammable chemicals, vapors, or particulates (including particles, dust, and metal powder) in the air.
- Do NOT expose the product to high concentrations of industrial chemicals, including liquefied gases that are easily vaporized (such as helium). Such exposure can damage or weaken the product's function.

### **Ingress Protection**

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

### **Operating Temperature**

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

### **Recommended Storage Conditions**

Store the product in a dry, well-ventilated place. The recommended ambient temperature is  $23 \pm 5^{\circ}\text{C}$ , and the humidity between 30% and 70%.

### **Light Interference**

Certain precision optical instruments may be interfered by the laser light emitted from the product. Please check all the instructions of these instruments and take preventive measures if necessary. For example, certain product models are equipped with protective covers, which can be used to block laser light emission when the product is temporarily not used for measurement.

## ■ 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 other people in the nearby environment wear medical devices (such as cochlear implants, heart pacemakers, and defibrillators), make sure to consult the physicians and medical device manufacturers for medical advice, such as determining whether it is safe to work near the product.
- 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 the *Specifications* section and the *Power Supply Requirements* section); 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 a humid environment.
- 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 breakdown, 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.

Please follow the standard laser safety guidelines accordingly.

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

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 cover lens can be regarded as the product's laser emitting window; looking at the cover lens can be regarded as looking into transmitting laser.

## Product Enclosure

- The product contains metal, glass, plastic, as well as sensitive electronic components. In case the product has been dropped and 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.
- The product contains 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 in case of 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: Cover Lens**

- Do NOT apply protective film, wax or any other substance on the cover lens.
- To keep the product's cover lens from fingerprints and other stains, do NOT touch the cover lens with bare hands. If the cover lens 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 cover lens 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 detection blind zone of lidar product. For questions on determining the detection blind zone, contact Hesai technical support.

### **Hot Surface**

During operation or a time period after 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 touch the product's enclosure with flammable materials.
- If a hot surface sign is provided on the product's enclosure, and that the product will be embedded into other equipment, 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 cover lens 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 cover lens.
- For each product model, the location of the cover lens is illustrated in the product's user manual (refer to the Introduction section).

### **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.

## **Custom Firmware and Software**

- Before using a custom version of firmware and software, please thoroughly understand the differences in functions and in performance between this custom version and the standard version.
- Make sure to strictly follow all the instructions and safety precautions provided for that custom 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 features, include but are not limited to: Noise Filtering, Interstitial Points Filtering, Retro Multi-Reflection Filtering, and Non-Linear Reflectivity Mapping.

These features 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 features. Moreover, users are responsible for analyzing the product's intended application scenarios and evaluating the risk of enabling one or more of these features in combination.

The supported features for this product model can be found on web control.

## **■ 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 personal injuries;
- shall constitute a breach of warranty.

# 1 Introduction

This manual describes the specifications, installation, and data format of AT128E2X.

## 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
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Figure 1.1 Distance Measurement Using Time of Flight

## 1.2 Lidar Structure

Shown in Figure 1.4, a rotating mirror is used to scan horizontally.

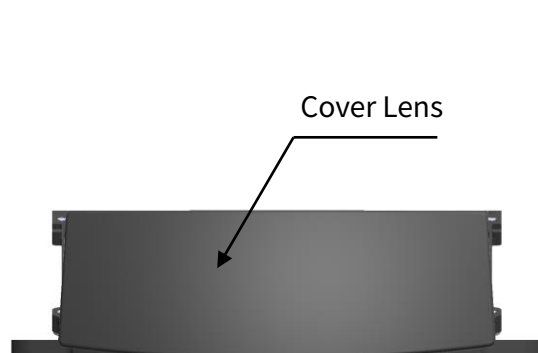


Figure 1.2 Front View

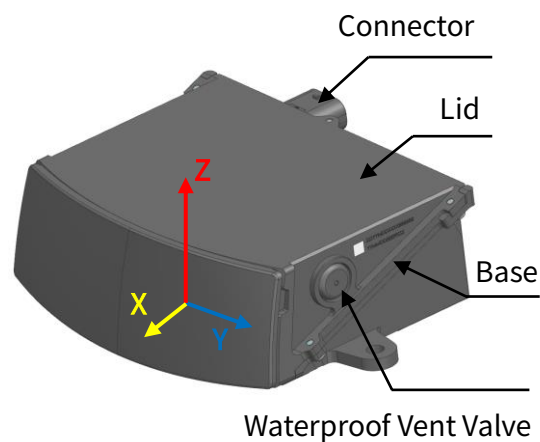


Figure 1.3 Coordinate System  
(Isometric View)

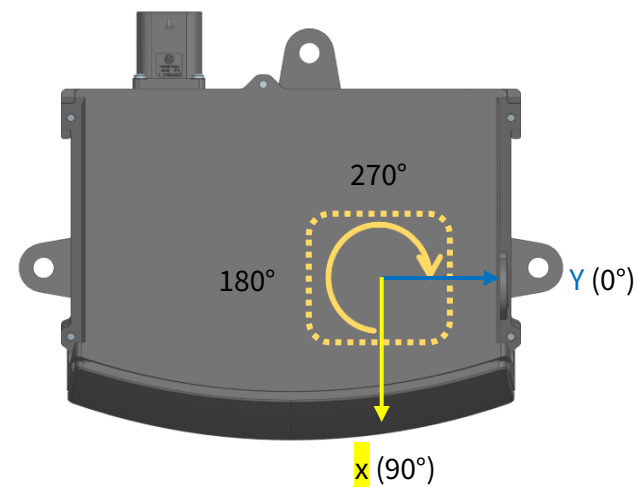


Figure 1.4 Mirror Rotation Direction  
(Top View)

The lidar's coordinate system is illustrated in Figure 1.3. Z-axis is the axis of rotation. The origin is shown in Figure 1.6 on the next page. All measurements are relative to the origin.

The mirror rotates clockwise in the top view (see Figure 1.4). Lidar azimuthal position is defined in Figure 1.4. Y-axis corresponds to 0°.

## 1.3 Channel Distribution

The designed vertical resolution is  $0.2^\circ$  across the FOV, as shown in Figure 1.5 and detailed in Appendix I (Channel Distribution)

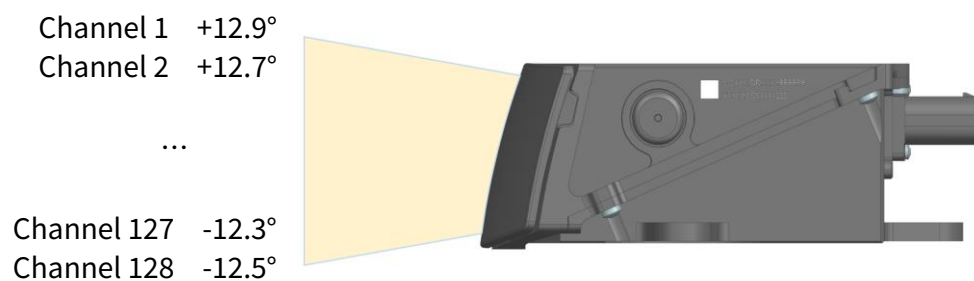


Figure 1.5 Channel Vertical Distribution

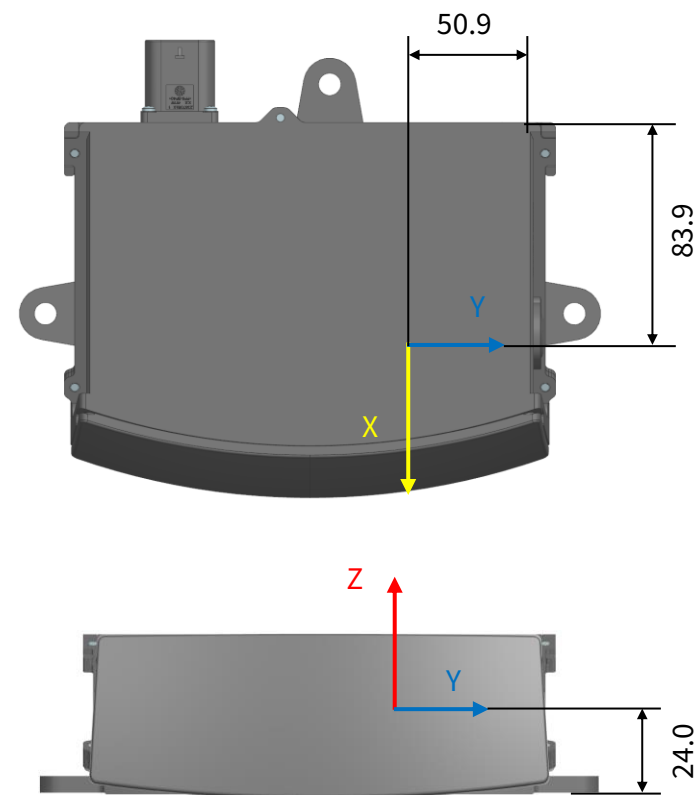



Figure 1.6 Origin of Coordinates (Unit: mm)

Each channel has an intrinsic angle offset, both horizontally and vertically.

The offsetted angles are recorded in this lidar unit's angle correction file (see Appendix III Angle Correction).

## 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)

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

(Continued on the next page)

MECHANICAL/ELECTRICAL/OPERATIONAL	
Wavelength	905 nm
Laser Class	Class 1 Eye Safe
Ingress Protection	IP6K7 & IP6K9K
Dimensions ①	137 x 112 x 48 mm
Rated Voltage Range②	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, Intensity
Valid Data Points ④	Single: 1,536,000 points/sec Dual: 3,072,000 points/sec
Point Cloud Data Rate ⑤	Single: 55.7 / 111.4 Mbps (avg/peak) Dual: 111.4 / 222.8 Mbps (avg/peak)
Clock Source	PTP
PTP Clock Accuracy	≤1 μs
PTP Clock Drift ⑥	≤5 μs/s

(Continued)

① Dimensions and Weight

- May be different for customized models. The mechanical drawings and weight data for customized models will be provided separately from this manual and such drawings and data 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).

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.
- The actual horizontal FOV of each mirror surface is slightly larger than  $120^\circ$ , so the actual data points are slightly more than the valid data points.

In Single Return mode:

- Given: horizontal FOV ( $120^\circ$ ), horizontal resolution ( $0.1^\circ$  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.

#### ⑤ Point Cloud Data Rate

- 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.

In Single Return mode:

- Given: horizontal FOV ( $120^\circ$ ), horizontal resolution ( $0.1^\circ$  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  $0.1^\circ$  azimuth; thus 1200 ( $120^\circ/0.1^\circ$ ) 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 =  $6000 * 1160 * 8 * 1E-6 \approx 55.7$  Mbps.

In Dual Return mode, point cloud average data rate is twice that in Single Return mode.

#### 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

💡 The information in this section be different for customized models. The mechanical drawings and weight data for customized models will be provided separately from this manual and such drawings and data shall prevail.

### 2.1 Mechanical Installation

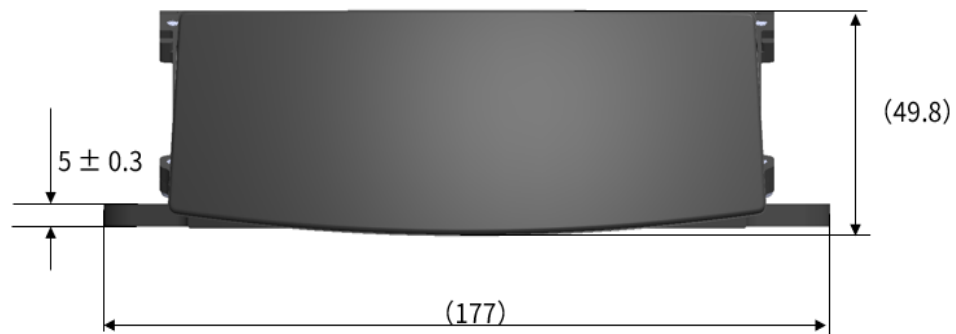


Figure 2.1 Front View (Unit: mm)

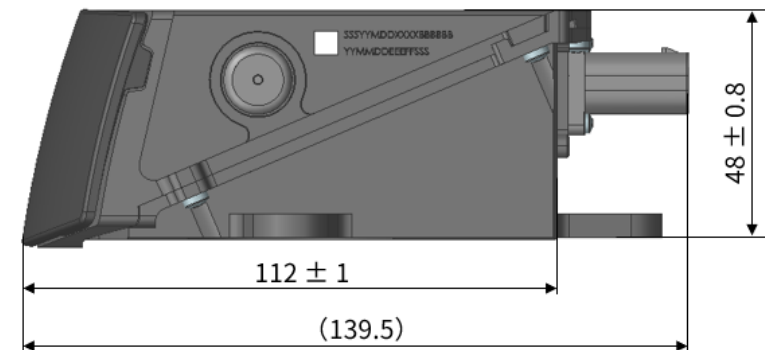


Figure 2.2 Right Side View (Unit: mm)

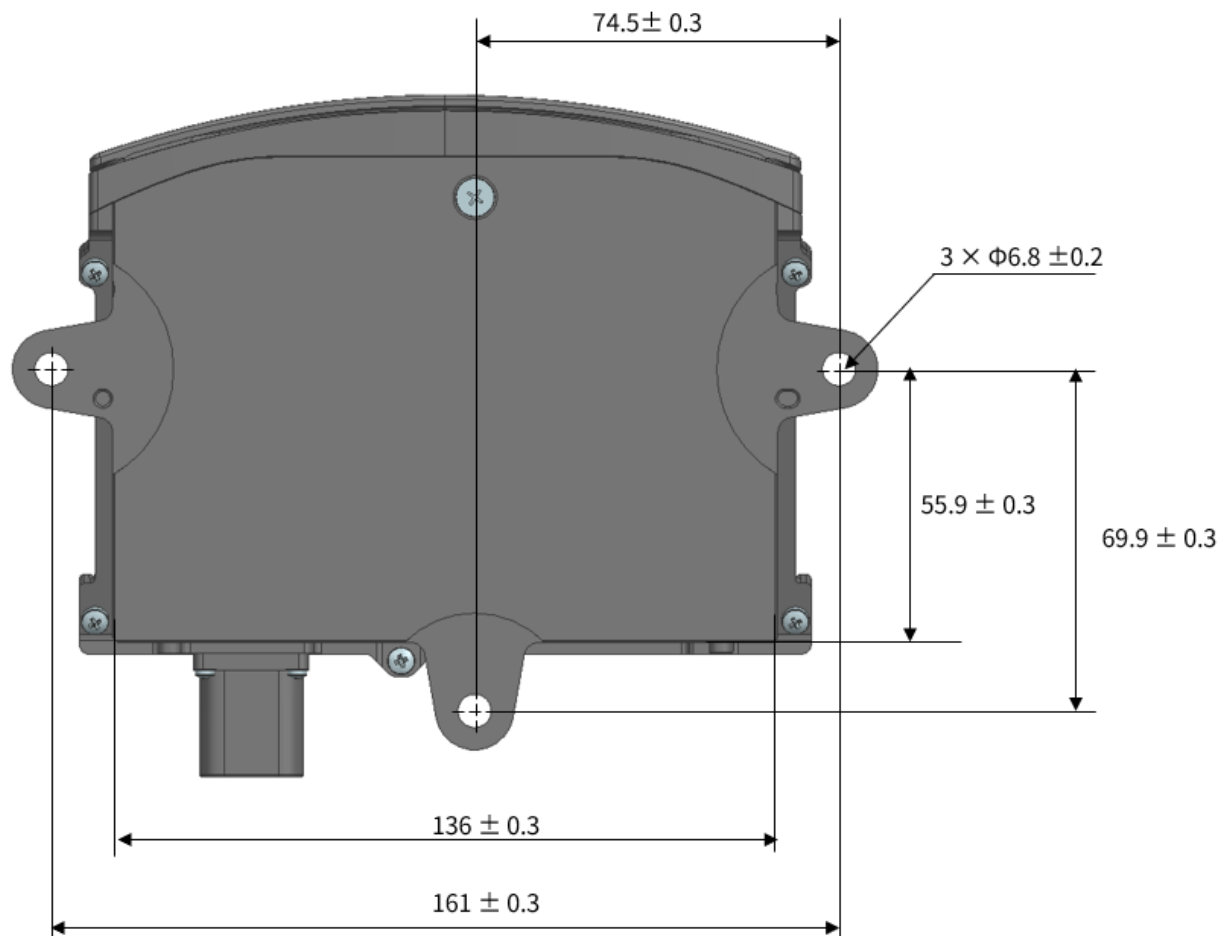


Figure 2.3 Bottom View (Unit: mm)

## 2.2 Interfaces

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

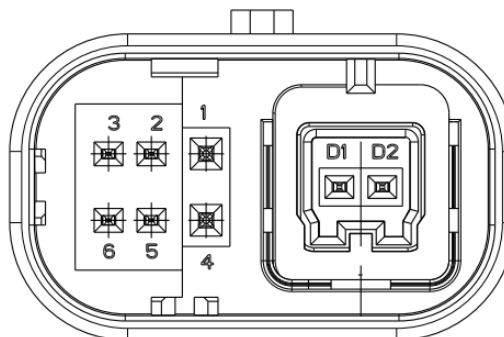



Figure 2.4 TE Connector (Male Socket): Dimensions and Pin Number

No.	Signal	Voltage
1	VCC	9 to 32 V (see NOTE below)
2	Reserved	-
3	Reserved	-
4	GND	0 V

No.	Signal	Voltage
5	Reserved	-
6	Reserved	-
D2	MDI-P	
D1	MDI-N	

### NOTE

- 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).

 Avoid touching the reserved wires or ports with bare hands.

## 2.2.1 Connector Use

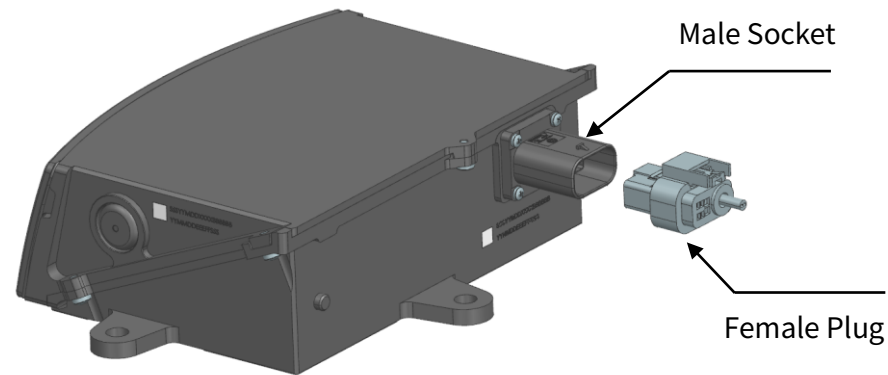


Figure 2.5 Connectors

Connection	Disconnection
<ul style="list-style-type: none"><li>• Turn off the power source.</li><li>• Make sure the plug's red locking clip is on the same side with the socket's latch.</li><li>• Push the plug straight into the socket until a click is heard.</li><li>• Push down the red locking clip to the bottommost position until a click is heard.</li></ul>	<ul style="list-style-type: none"><li>• Turn off the power source.</li><li>• Pull up the red locking clip with your fingernail until a click is heard.</li><li>• Push down the black clip and pull the plug from the socket.</li></ul>

### Warnings

- 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.
- In case a 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.

### 2.2.2 Cables (Ethernet)

OD (outside diameter) =  $4.10 \pm 0.20$  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.

The connection box has a power port and a standard Ethernet port.

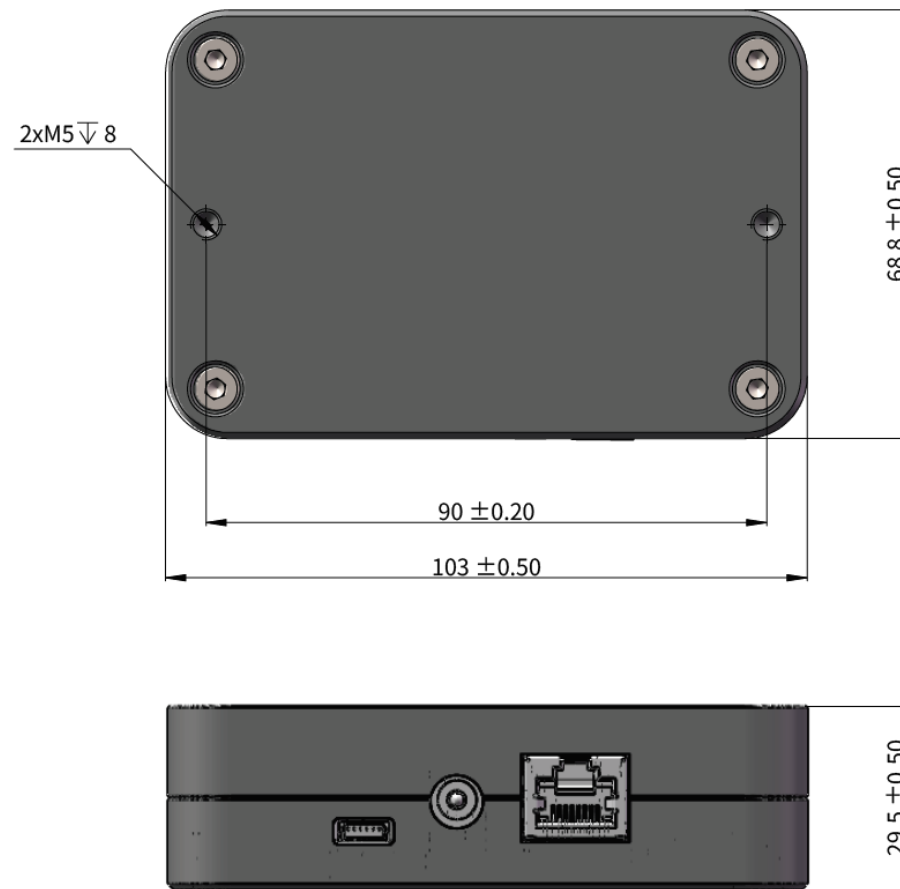


Figure 2.6 Connection Box (Unit: mm)

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

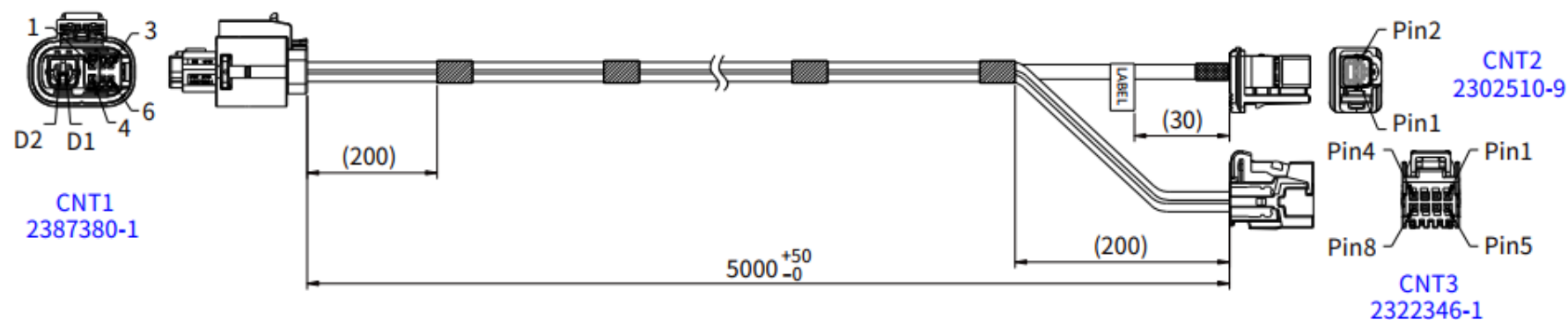


Figure 2.7 Cable between Lidar and Connection Box

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 <sup>2</sup>
Pin 4	Pin 8	GND	Black	0.75 mm <sup>2</sup>
Pin # on CNT1 Connector	Pin # on CNT2 Connector	Signal	Wire Color	
D2	Pin 1	MDI-P	White	
D1	Pin 2	MDI-N	Green	

2.3.1 Connection Box Interfaces

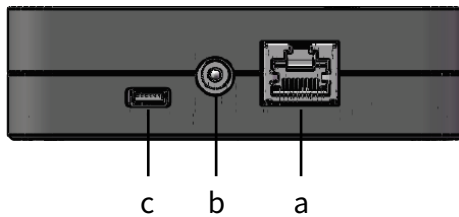


Figure 2.8 Connection Box (Front)

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

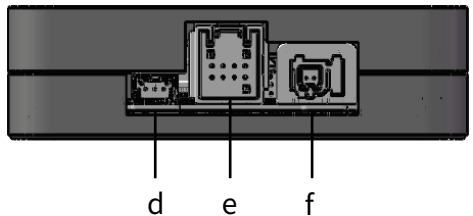


Figure 2.9 Connecting Box (Back)

Port #	Port Name	Description
d	Reserved Port	Do not connect this port to external signals
e	Power Output Port	See CNT3 connector in Figure 2.6
f	Automotive Ethernet Port	See CNT2 connector in Figure 2.6



### 2.3.2 Connection

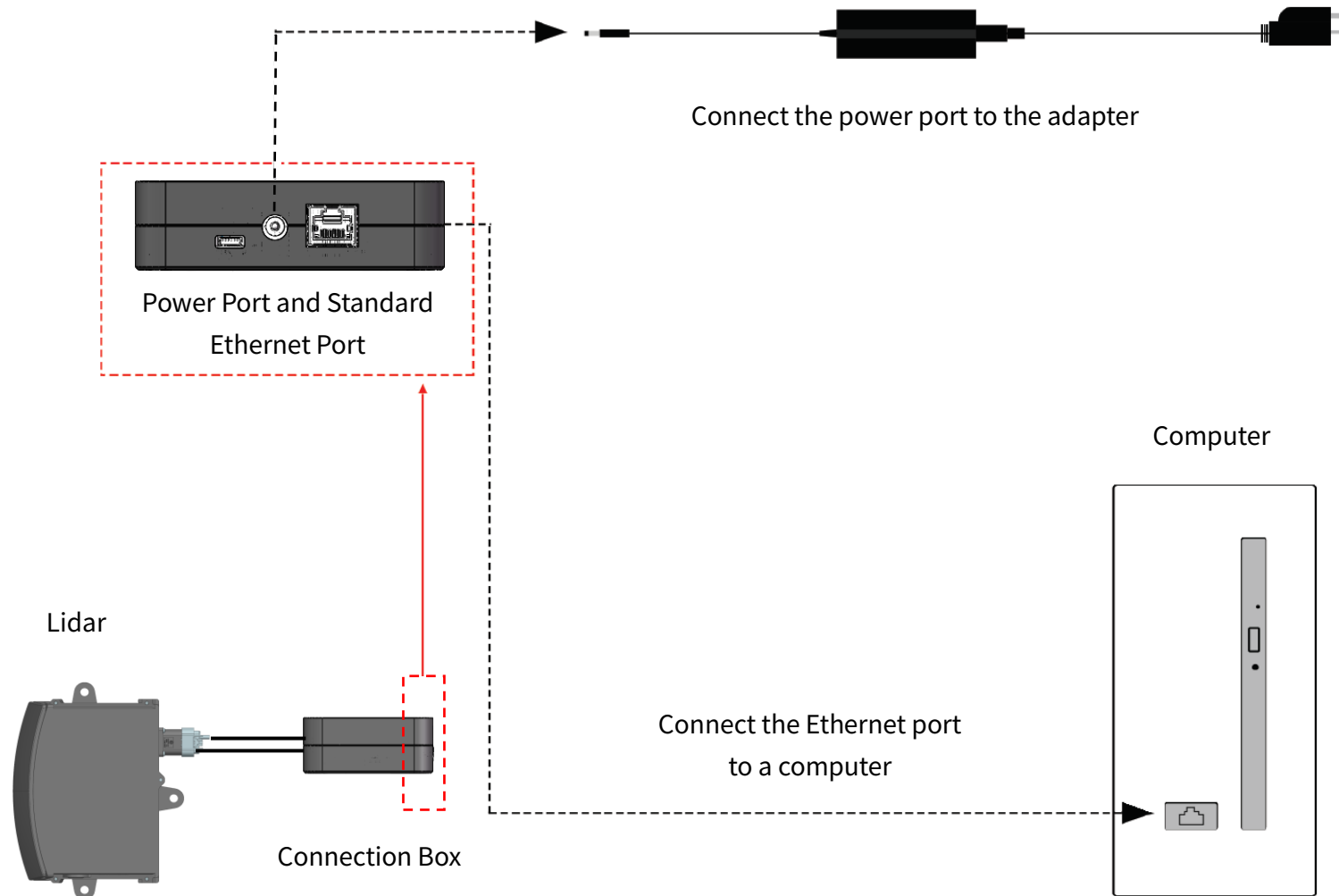


Figure 2.10 Connection with PTP (Software Simulation)

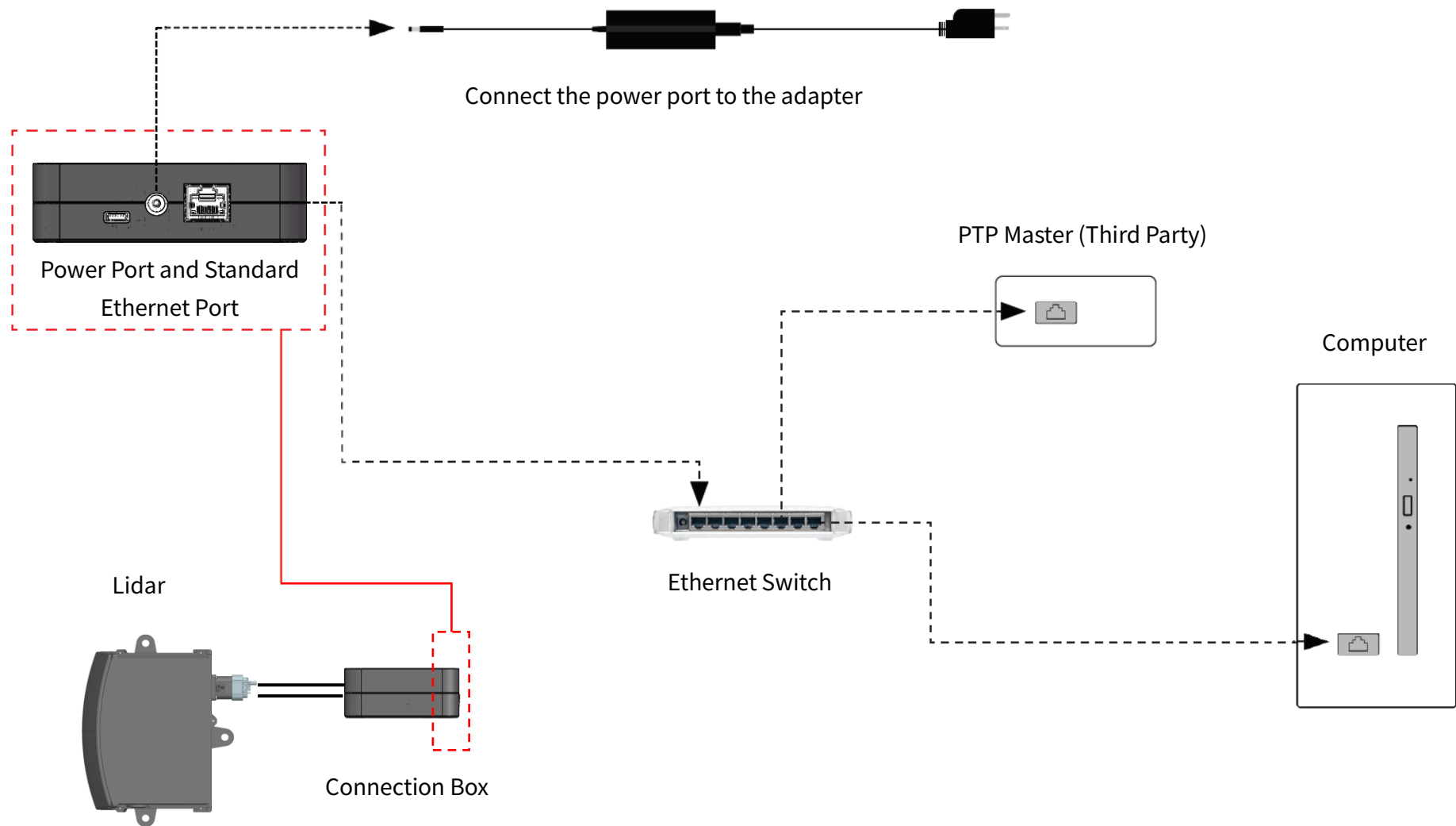


Figure 2.11 Connection with PTP (Hardware Device)

## 2.4 Get Ready to Use

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 192.168.1.100 and subnet mask to 255.255.255.0

For Ubuntu:	For Windows:
Input this ifconfig command in the terminal: ~\$ sudo ifconfig enp0s20f0u2 192.168.1.100 (replace enp0s20f0u2 with the local Ethernet port name)	Open the Network Sharing Center, click on "Ethernet" In the "Ethernet Status" box, click on "Properties" Double-click on "Internet Protocol Version 4 (TCP/IPv4)" Configure the IP address to 192.168.1.100 and subnet mask to 255.255.255.0

To record and display point cloud data, please contact Hesai Technology technical support.

To set parameters, check device info, or upgrade firmware/software (see Section 4 Web Control).

To obtain the SDKs (Software Development Kits) for your product model, please contact Hesai Technology technical support.

### 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.

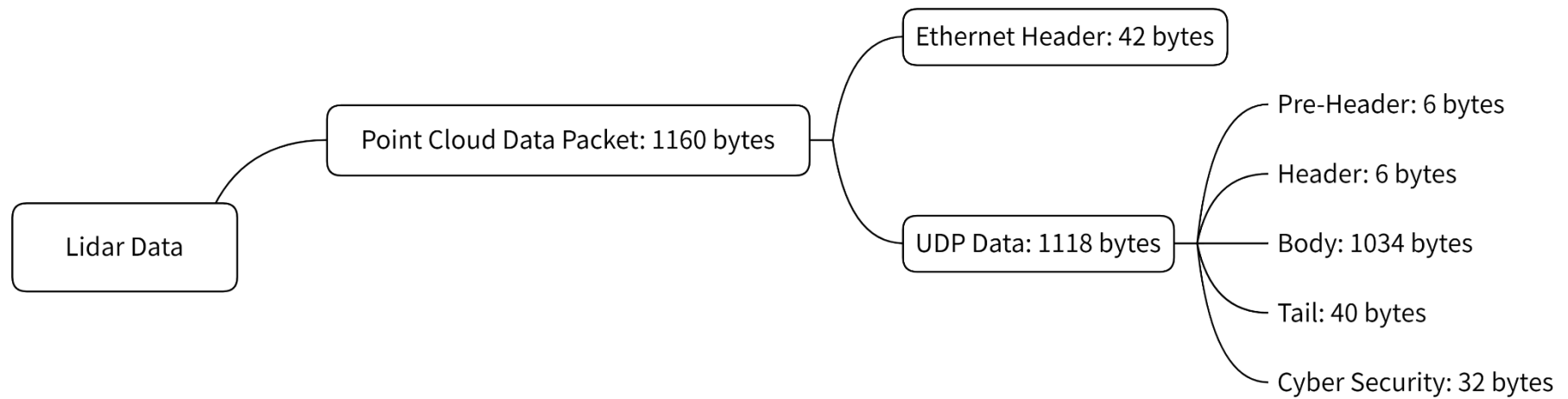


Figure 3.1 Data Structure

## 3.1 Point Cloud Data Packet

### 3.1.1 Ethernet Header

The destination IP is 255.255.255.255 (broadcast) by default.

Point Cloud Ethernet Header: 42 bytes		
Field	Bytes	Description
Ethernet II MAC	12	Destination: broadcast (0xFF: 0xFF: 0xFF: 0xFF: 0xFF: 0xFF) Source: (xx:xx:xx:xx:xx:xx)
Ethernet Data Packet Type	2	0x08, 0x00
Internet Protocol	20	Shown in the figure below
UDP Port Number	4	UDP source port (0x2710 by default, representing 10000) Destination port (0x0940 by default, representing 2368)
UDP Length	2	0x0466, representing 1126 bytes
UDP Checksum	2	-

```
▼ Internet Protocol Version 4, Src: 192.168.20.51, Dst: 255.255.255.255
  0100 .... = Version: 4
  .... 0101 = Header Length: 20 bytes (5)
  > Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
    Total Length: 889
    Identification: 0xcd2b (52523)
  > Flags: 0x4000, Don't fragment
    Fragment offset: 0
    Time to live: 64
    Protocol: UDP (17)
    Header checksum: 0x94ca [validation disabled]
    [Header checksum status: Unverified]
    Source: 192.168.20.51
    Destination: 255.255.255.255
```

Figure 3.2 Point Cloud Ethernet Header - Internet Protocol

### 3.1.2 UDP Data

#### ■ Pre-Header: 6 bytes

Field	Bytes	Description
0xEE	1	SOP (start of packet)
0xFF	1	SOP (start of packet)
Protocol Version Major	1	Main class of the point cloud UDP packet structure Currently 0x04
Protocol Version Minor	1	Subclass of the point cloud UDP packet structure Currently 0x03
Reserved	2	-

#### ■ Header: 6 bytes

Field	Bytes	Description
Laser 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.)
Flags	1	<div> <div> [7:4] is reserved  [3] digital signature  [2] functional safety  [1] IMU  [0] UDP sequence </div> <div> 1 - YES  1 - YES  1 - YES  1 - YES </div> <div> 0 - NO  0 - NO  0 - NO  0 - NO </div> </div>

■ **Body: 1034 bytes (2 blocks)**

Field	Bytes	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, used as the current reference angle of the rotor.
Fine Azimuth 1	1	For Block 1: High-resolution part of the encoder angle Unit: 0.01° / 256 Encoder angle of Block 1 = <b>Azimuth 1</b> * 0.01° + <b>Fine Azimuth 1</b> * 0.01° / 256 💡 To convert from encoder angle to point cloud horizontal angle (see Appendix III Angle Correction).
Block 1	512	For Block 1: measurements made by each channel, starting form Channel 1 (see table below)
Azimuth 2	2	For Block 2
Fine Azimuth 2	1	
Block 2	512	
CRC 1	4	CRC-32 checksum of the Body

Each Block in the Body: 4 * 128 = 512 bytes			
Field	Bytes	Description	
Channel X	4	2-byte Distance	Distance Value = Distance * Dis Unit 💡 Dis Unit is specified in the "Header" in this section.
		1-byte Reflectivity	Reflectivity Value = Reflectivity * 1% Range: 0 to 255
		1-byte Confidence	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 number block is the last return, and the even number block is the strongest return
- If the last and strongest returns coincide, the second strongest return will be placed in the even number block
- The Azimuth (encoder angle) changes every two blocks


Point Cloud Data Packet (Single Return)	
Block 1	Block 2
Return from this round of firing	Return from the next round of firing

Point Cloud Data Packet (Dual Return)	
Block 1	Block 2
Last return	Strongest return

Point Cloud Data Packet (Dual Return)	
Block 1	Block 2
Last and strongest return	Second strongest return




■ Tail: 40 bytes

Field	Bytes	Description
Reserved	6	-
High Temperature Shutdown Flag	1	<p>0x01 for high temperature; 0x00 for normal operation.</p> <ul style="list-style-type: none"> <li>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.</li> <li>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.</li> </ul>
Reserved	11	-
Motor Speed	2	<p>Spin rate of the motor Signed integer Define clockwise in the top view as positive Unit: 0.1 rpm</p> <p> <b>Note</b></p> <ul style="list-style-type: none"> <li>By default, each of the three mirror surfaces corresponds to one point cloud frame. Thus for every motor rotation, three frames are generated.</li> <li>Spin rate of the motor (rpm) = frame rate (Hz) * (60/3)</li> <li>Real-time motor speed is shown on the Home page of web control (see Section 4.1).</li> </ul>
Timestamp	4	<p>The "μs time" part of the absolute time of this data packet (defined in Appendix II) Unit: μs Range: 0 to 999999 μs (1 s)</p>
Return Mode	1	<p>0x37 for Strongest Return mode, 0x38 for Last Return mode 0x39 for Dual Return mode (Last, Strongest)</p>
Factory Information	1	0x42

Field	Bytes	Description				
Date & Time	1*6	<div>Relative UTC time of this data packet, accurate to the second. In big endian format:</div> <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> <div>💡 Refer to Appendix II (Absolute time of Point Cloud Data).</div>	Byte 1	0x00 (fixed)	Byte 2 to 6	Number of seconds since the Unix epoch (1970-01-01 00:00:00 UTC)
Byte 1	0x00 (fixed)					
Byte 2 to 6	Number of seconds since the Unix epoch (1970-01-01 00:00:00 UTC)					
UDP Sequence	4	<div>Sequence number of this UDP packet 0 to 0xFF FF FF FF</div>				
CRC 2	4	CRC-32 checksum of the Tail				

## ■ Cyber Security

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

### 3.1.3 Point Cloud Data Analysis

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

#### ■ 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 III (Angle Correction).

$0^\circ$  represents the horizontal direction

Define upward as positive

Channel # from the uppermost counts from 1

- 2) Calculate the horizontal angle ( $h\_angle$ ) of Channel 5 according to Appendix III (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.

$$h\_angle1 = h\_angle + \text{firing time angular offset}$$

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

- Firing time offset: in units of s (seconds); see Appendix II Laser Firing Time.
- Spin rate of the motor: in units of  $^\circ/\text{s}$  (degrees per second); see Section 4.1 Web Control – Home.

### ■ Analyze the distance of a data point

Actual distance in real world millimeters = distance measurement \* Distance Unit

- Distance measurement: Distance field of Channel 5 in Block 2.
- Distance Unit: Dis Unit field in the Header of Point Cloud Data Packets.

### ■ 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.

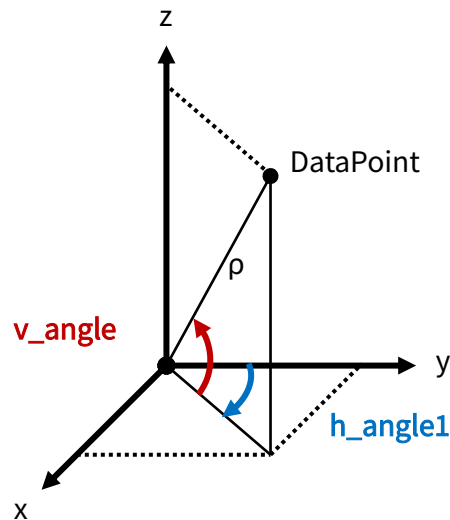


Figure 3.3 Horizontal and Vertical Angles of a Data Point

### ■ 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

 Google Chrome and Mozilla Firefox are recommended.

## 4.1 Home

Status	
Spin Rate	200 rpm
PTP	Free Run
Device Info	
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

Parameter	Description								
Spin Rate	Spin Rate: 200/400 rpm Detailed in the Motor Speed field in Section 3.1.2 (Point Cloud UDP Data).								
PTP	<div>PTP status</div> <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 (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>	Free Run	No PTP master is selected.	Tracking	Attempting to sync with the selected PTP Master, but the absolute offset exceeds the user-specified limit in Section 4.2 (Settings).	Locked	Absolute offset is within the user-specified limit.	Frozen (Holdover)	Attempting to recover the connection to the PTP master.
Free Run	No PTP master is selected.								
Tracking	Attempting to sync with the selected PTP Master, but the absolute offset exceeds the user-specified limit in Section 4.2 (Settings).								
Locked	Absolute offset is within the user-specified limit.								
Frozen (Holdover)	Attempting to recover the connection to the PTP master.								
Firmware Version	Version number of FPGA								
RPU Version	Version number of RPU RPU (real-time processing unit) is mainly used in: <ul style="list-style-type: none"> <li>• Diagnosis for functional safety</li> <li>• Loading and configuration for point cloud parameters</li> </ul>								
Nominal Voltage	<ul style="list-style-type: none"> <li>• Lidar with 24 V nominal voltage: DC 9 to 32 V.</li> <li>• Lidar with 12 V nominal voltage: DC 9 to 16 V.</li> </ul>								
PHY Mode	Communication mode for automotive Ethernet (1000Base-T1) <ul style="list-style-type: none"> <li>• Master</li> <li>• Slave (by default)</li> </ul>								

## 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

(Continued on the next page)





(Continued)

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: <ul style="list-style-type: none"> <li>• Section 4.2 (Settings))</li> </ul>
Save	Save and execute all the settings on this page. <ul style="list-style-type: none"> <li>• Exception: Standby Mode takes effect immediately without having to click "Save".</li> </ul>

### 4.2.1 Network Settings

Parameter	Options	Description
VLAN	Default: OFF VLAN ID: 1 to 4094	<p>To enable VLAN tagging:</p> <ul style="list-style-type: none"> <li>• Make sure the receiving host also supports VLAN.</li> <li>• Check the checkbox and input the lidar's VLAN ID (same as the receiving host's VLAN ID).</li> </ul> <p> <b>Warnings</b></p> <ul style="list-style-type: none"> <li>• If the lidar's VLAN ID differs from the receiving host's, users will lose access to web control.</li> </ul> <p> <b>Notes</b></p> <ul style="list-style-type: none"> <li>• Once configured, the VLAN ID does not change during firmware upgrades.</li> </ul>

Parameter	Options	Description	
Destination IP	Any address except for 0.0.0.0, 127.0.0.1, and the lidar's IP.  Default: 255.255.255.255		
		Mode	Destination IP
		Broadcast (default)	255.255.255.255
		Multicast	User-defined
		Unicast	Same as the PC's IP address
Lidar Destination Port	Default: 2368	Destination port of Point Cloud Data Packets	
Fault Message Destination Port	Default: 2368	Destination port of fault messages	

## 4.2.2 Function Settings

Parameter	Options	Description
Spin Rate	200/400 RPM Default: 200 RPM	The set spin rate is also shown on web control (see Section 4.1 Web Control – Home).
Return Mode	Single Return <ul style="list-style-type: none"> <li>Last</li> <li>Strongest (default)</li> </ul> Dual Return <ul style="list-style-type: none"> <li>Last and Strongest</li> </ul>	Also shown in Point Cloud Data Packets (see the Return Mode field in Section 3.1.2 Point Cloud UDP Data).

Parameter	Options	Description				
Sync Angle	30° to 150°	<p>Phase lock angle</p> <ul style="list-style-type: none"><li>To activate this function, check the checkbox and input an azimuth.</li><li>At every full second, the lidar will rotate to that azimuthal position (see Section 1.2 Lidar Structure).</li></ul> <p>Definition of full second</p> <ul style="list-style-type: none"><li>When PTP is tracking or locked: retrieved from the PTP master clock</li><li>Otherwise: the rising edge of the lidar's internal 1 Hz signal</li><li>Detailed in Appendix II (Absolute Time of Point Cloud Data)</li></ul> <p>To phase-lock multiple lidars</p> <p>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.</p>				
Trigger Method	Angle-Based (default) Time-Based	<p>The way laser firings are triggered.</p> <table><tr><td>Angle-based</td><td>Lasers fire every 0.1° at 10 Hz.</td></tr><tr><td>Time-based</td><td>Lasers fire every 41.666 us.</td></tr></table>	Angle-based	Lasers fire every 0.1° at 10 Hz.	Time-based	Lasers fire every 41.666 us.
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.				

State	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	<b>PTP</b>
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	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				
		<table><tr><td>UDP/IP</td><td>Available only for 1588v2 profile</td></tr><tr><td>L2</td><td>Available for all profiles</td></tr></table>	UDP/IP	Available only for 1588v2 profile	L2	Available for all profiles
		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 files.
- During the upgrade, it is recommended to place a protective cover (supplied with the lidar) or other opaque material over the lidar's cover lens.

### Upgrade

- Click the "Upload" button, select an upgrade file, and confirm your choice in the pop-up window.
- When the upgrade is complete, the lidar will automatically reboot, and the past versions will be logged in the Upgrade Log.

Button	Description
Restart	Software reboot Afterwards, the Start-Up Counts in the Operation Statistics page increments by 1.

Parameter	Current Value	Description
Software Version	3.50.15	-
Firmware Version	3.10b830	Version number of FPGA
RPU Version	3.50.008	Version number of RPU RPU (real-time processing unit) is mainly used in: <ul style="list-style-type: none"><li>• Diagnosis for functional safety</li><li>• Loading and configuration for point cloud parameters</li></ul>
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 in 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

timestamp20: 4252631040

timestamp21: 4253089795

event\_state: 3

status\_data:

00000000000000002f7f070000000000400000002f7f070000000000400000004000000000

freeze\_frame\_1:

## 4.6 Log

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

Parameter	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

### ■ Cleaning

Stains on the product's cover lens, such as dirt, fingerprints, and oil, can negatively affect point cloud data quality. Please perform the following steps to remove the stains.

### ⚠ Warnings

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

### 💡 Notes

- Only clean the stained area of the cover lens.
  - Check before using a lint-free wipe. If the wipe is stained, use another.
- 1) Thoroughly wash your hands or wear a pair of powder-free PVC gloves.
  - 2) To remove dust, blow dry air onto the cover lens, or use a piece of lint-free wipe to lightly brush across the dusty area.  
To remove persistent stains, move on to the next step.
  - 3) Spray the cover lens with warm, neutral solvent using a spray bottle.

Solvent type	Soft sponge with a mild soap solution 💡 Mild soap solution: maximum two tablespoons of neutral soap in 1 quart (1 liter) of water.
Solvent temperature	20 to 25°C

(Continued on the next page)

(Continued)

- 4) When the stains have loosened, dip a piece of lint-free wipe into the solvent made in Step 3, and gently wipe the cover lens 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 cover lens with clean water, and gently wipe off the remaining liquid with another piece of lint-free wipe.

## 7 Troubleshooting

In case the following procedures cannot solve the problem, please contact Hesai technical support.

Symptoms	Points to Check
Indicator light is off on the connection box	<p>Verify that:</p> <ul style="list-style-type: none"><li>• power adapter is properly connected and in good condition;</li><li>• connection box is intact;</li><li>• input voltage and current satisfy the requirements in Section 2.3 (Connection Box).</li></ul> <p>Power on again to check if the symptom persists.</p>
Motor is not running	<p>Verify that:</p> <ul style="list-style-type: none"><li>• power adapter is properly connected and in good condition;</li><li>• if a connection box is used, the connection box is intact;</li><li>• input voltage and current satisfy the requirements in Section 1.4 (Specifications) and 2.3 (Connection Box);</li><li>• web control can be accessed (see "cannot open web control" on the next page);</li><li>• the lidar is not in standby mode (see Section 4.2 Web Control – Settings).</li></ul> <p>Power on again to check if the symptom persists.</p>

Symptoms	Points to Check
Motor is running but no output data is received, neither on Wireshark nor on PandarView	<p>Verify that:</p> <ul style="list-style-type: none"> <li>• Ethernet cable is properly connected (by unplugging and plugging again)</li> <li>• Lidar's Destination IP is correctly set on the Settings page of web control</li> <li>• firmware version of the sensor is correctly shown on the Upgrade page of web control</li> <li>• Lidar is emitting laser light. This can be checked by using an infrared camera, an infrared sensor card, or a phone camera without infrared filter</li> </ul> <p>If a connection box is used:</p> <ul style="list-style-type: none"> <li>• replace the current Ethernet cable with another cable of at least Cat 6; Cat 7 or higher is recommended.</li> </ul> <p>Power on again to check if the symptom persists.</p>
Can receive data on Wireshark but not on PandarView	<p>Verify that:</p> <ul style="list-style-type: none"> <li>• the Lidar Destination Port is set correctly on the Settings page of web control</li> <li>• PC's firewall is disabled, or that PandarView is added to the firewall exceptions</li> <li>• if VLAN is enabled, the PC's VLAN ID is the same with the lidar's</li> <li>• the latest PandarView version (see the Download page of Hesai's official website or contact Hesai technical support) is installed on the PC</li> </ul> <p>Power on again to check if the symptom persists.</p>



Symptoms	Points to Check
Cannot open web control	<p>Verify that</p> <ul style="list-style-type: none"> <li>• Ethernet cable is properly connected (by unplugging and plugging again)</li> <li>• Lidar's IP is in the same subnet with the PC's. Users may use WireShark to check the lidar's IP that broadcasts data packets</li> <li>• if VLAN is enabled, the PC's VLAN ID is the same with the lidar's</li> </ul> <p>Afterwards,</p> <ul style="list-style-type: none"> <li>• restart PC, or connect the lidar to another PC</li> <li>• power on again to check if the symptom persists</li> </ul>
Abnormal packet size (missing packets)	<p>Verify that</p> <ul style="list-style-type: none"> <li>• motor's spin rate is steady on the Home page of web control</li> <li>• Lidar's internal temperature is between -40°C and 110°C on the Operation Statistics page of web control</li> <li>• Ethernet is not overloaded</li> <li>• no switch is connected into the network. The data transmitted from other devices may cause network congestion and packet loss</li> </ul> <p>Afterwards,</p> <ul style="list-style-type: none"> <li>• connect the PC only to the lidar and check for packet loss</li> <li>• power on again to check if the symptom persists</li> </ul>

Symptoms	Points to Check
Abnormal point cloud (obviously misaligned points, flashing points, or incomplete FOV)	<p>Verify that</p> <ul style="list-style-type: none"> <li>• Lidar's cover lens is clean. If not, refer to Chapter 6 (Sensor Maintenance) for the cleaning method</li> <li>• Lidar's calibration file is imported; see <i>PandarView User Manual</i> (Use)</li> <li>• motor's spin rate is steady on the Home page of web control</li> <li>• Lidar's internal temperature is between -40°C and 110°C on the Operation Statistics page of web control</li> </ul> <p>Afterwards, check for packet loss</p> <ul style="list-style-type: none"> <li>• If no packet is missing and yet the point cloud flashes, please update PandarView to the latest version (see the Download page of Hesai's official website or contact Hesai technical support) and restart the PC</li> </ul> <p>If the point cloud is still abnormal</p> <ul style="list-style-type: none"> <li>• Try connecting the lidar to another PC</li> <li>• Power on again to check if the symptom persists</li> </ul>

# Appendix I Channel Distribution

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	Far Field Enhanced?
	Horiz. Offset	Vertical	Min	Max			
①	②	③	④	⑤	⑥	⑦	⑧

①	Channel # counts from 1, from the top to bottom
② ③	Design values of each channel's horizontal (azimuth) angle offset and vertical (elevation) angle. <ul style="list-style-type: none"> <li>The accurate values are recorded in this lidar's unit's calibration file.</li> <li>Refer to Section 3.1.3 (Point Cloud Data Analysis) for the data parsing scheme.</li> </ul>
④ ⑤	Actual measurement range, confined by the allocated Time of Flight (ToF) for each channel
⑥	The 32 channels with ④ = 0.5 m are <b>NF-enabled channels</b> . <ul style="list-style-type: none"> <li>All channels fire laser pulses that measure the far field (<math>&gt; 7.2</math> m).</li> <li>Additionally, the NF-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.</li> <li>The horizontal resolution of NF measurement is always <math>0.2^\circ</math> at 10 Hz and <math>0.4^\circ</math> at 20 Hz.</li> </ul>
⑦	The values in brackets only indicate detection capability, while the actual measurement range is cut off to ⑤. Channels 97 to 128 have enhanced near- and mid-field detection, since these channels typically point to the ground in the far field.
⑧	Channels 33 to 96 are <b>FF-enhanced channels</b> , which are able to detect 180 m@10% (see data in ⑦).

Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	Far Field Enhanced?
	Horiz. Offset	Vertical	Min	Max			
01 (Top)	2.4	12.93	7.2 m	100 m	-	-	-
02	-0.65	12.73	7.2 m	100 m	-	-	-
03	2.4	12.53	0.5 m	100 m	YES	-	-
04	-0.65	12.33	7.2 m	100 m	-	-	-
05	2.4	12.13	7.2 m	100 m	-	-	-
06	-0.65	11.93	7.2 m	100 m	-	-	-
07	2.4	11.73	0.5 m	100 m	YES	-	-
08	-0.65	11.53	7.2m	100 m	-	-	-
09	2.4	11.33	7.2 m	100 m	-	-	-
10	-0.65	11.13	7.2 m	100 m	-	-	-
11	2.4	10.93	0.5 m	100 m	YES	-	-
12	-0.65	10.73	7.2 m	100 m	-	-	-
13	2.4	10.53	7.2 m	100 m	-	-	-
14	-0.65	10.33	7.2 m	100 m	-	-	-
15	2.4	10.13	0.5 m	100 m	YES	-	-
16	-0.65	9.93	7.2 m	100 m	-	-	-
17	-2.4	9.73	7.2 m	100 m	-	-	-
18	0.65	9.53	7.2 m	100 m	-	-	-
19	-2.4	9.33	0.5 m	100 m	YES	-	-
20	0.65	9.13	7.2 m	100 m	-	-	-

Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	Far Field Enhanced?
	Horiz. Offset	Vertical	Min	Max			
21	-2.4	8.93	7.2 m	100 m	-	-	-
22	0.65	8.73	7.2 m	100 m	-	-	-
23	-2.4	8.53	0.5 m	100 m	YES	-	-
24	0.65	8.33	7.2 m	100 m	-	-	-
25	-2.4	8.13	7.2 m	100 m	-	-	-
26	0.65	7.93	7.2 m	100 m	-	-	-
27	-2.4	7.73	0.5 m	100 m	YES	-	-
28	0.65	7.53	7.2 m	100 m	-	-	-
29	-2.4	7.33	7.2 m	100 m	-	-	-
30	0.65	7.13	7.2 m	100 m	-	-	-
31	-2.4	6.93	0.5 m	100 m	YES	-	-
32	0.65	6.73	7.2 m	100 m	-	-	-
33	2.4	6.53	7.2 m	100 m	-	-	-
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 Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	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 Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	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	7.2m	200 m	-	180 m	YES
63	-2.4	0.53	7.2 m	200 m	-	180 m	YES
64	0.65	0.33	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
68	-0.65	-0.47	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
72	-0.65	-1.27	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
76	-0.65	-2.07	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
80	-0.65	-2.87	0.5 m	200 m	YES	180 m	YES

Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	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	7.2 m	200 m	-	180 m	YES
84	0.65	-3.67	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
88	0.65	-4.47	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
92	0.65	-5.27	0.5 m	200 m	YES	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	7.2 m	200 m	-	180 m	YES
96	0.65	-6.07	0.5 m	200 m	YES	180 m	YES
97	2.4	-6.27	7.2 m	100 m	-	180 m	YES
98	-0.65	-6.47	7.2 m	100 m	-	-	-
99	2.4	-6.67	7.2 m	100 m	-	-	-
100	-0.65	-6.87	0.5 m	100 m	YES	-	-



Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	Far Field Enhanced?
	Horiz. Offset	Vertical	Min	Max			
101	2.4	-7.07	7.2 m	100 m	-	-	-
102	-0.65	-7.27	7.2 m	100 m	-	-	-
103	2.4	-7.47	7.2 m	100 m	-	-	-
104	-0.65	-7.67	0.5 m	100 m	YES	-	-
105	2.4	-7.87	7.2 m	100 m	-	-	-
106	-0.65	-8.07	7.2 m	100 m	-	-	-
107	2.4	-8.27	7.2 m	100 m	-	-	-
108	-0.65	-8.47	0.5 m	100 m	YES	-	-
109	2.4	-8.67	7.2 m	100 m	-	-	-
110	-0.65	-8.87	7.2 m	100 m	-	-	-
111	2.4	-9.07	7.2 m	100 m	-	-	-
112	-0.65	-9.27	0.5 m	100 m	YES	-	-
113	-2.4	-9.47	7.2 m	100 m	-	-	-
114	0.65	-9.67	7.2 m	100 m	-	-	-
115	-2.4	-9.87	7.2 m	100 m	-	-	-
116	0.65	-10.07	0.5 m	100 m	YES	-	-
117	-2.4	-10.27	7.2 m	100 m	-	-	-
118	0.65	-10.47	7.2 m	100 m	-	-	-
119	-2.4	-10.67	7.2 m	100 m	-	-	-
120	0.65	-10.87	0.5 m	100 m	YES	-	-

Channel Distribution (Continued)

Channel #	Angular Position		Instrument Range		Near Field Enabled?	Max. Range @10% Reflectivity (PoD = 50%)	Far Field Enhanced?
	Horiz. Offset	Vertical	Min	Max			
121	-2.4	-11.07	7.2 m	100 m	-	-	-
122	0.65	-11.27	7.2 m	100 m	-	-	-
123	-2.4	-11.47	7.2 m	100 m	-	-	-
124	0.65	-11.67	0.5 m	100 m	YES	-	-
125	-2.4	-11.87	7.2 m	100 m	-	-	-
126	0.65	-12.07	7.2 m	100 m	-	-	-
127	-2.4	-12.27	7.2 m	100 m	-	-	-
128 (Bottom)	0.65	-12.47	0.5 m	100 m	YES	-	-

# Appendix II Absolute Time of Point Cloud Data

## ■ Source of Absolute Time

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

- The lidar connects to a third-party PTP master to obtain the absolute time.
- Users may configure the PTP settings (see Section 4.2 Web Control – Settings).
- Users may check the PTP signal status (see Section 4.1 Web Control - Home).
- The lidar does not output GPS Data Packets.

The absolute time is updated as follows.

PTP Status	Date & Time (accurate to $\mu$ s)	Description
Free Run	Virtual	Starts counting from a virtual UTC time (such as 2000-01-01 00:00:00), using the lidar's internal 1 Hz signal.
Tracking or Locked	Synchronized	Extract the actual date and time from the PTP Master's messages.
Frozen	Drifting	Starts counting from the last synchronized time, using the lidar's internal 1 Hz signal. Will gradually drift from the actual PTP time.



## Notes

- 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.

## ■ Absolute Time of Point Cloud Data Packets

The absolute time of a Point Cloud Data Packet (denoted as  $t_0$ ) is calculated as follows:

$$t_0 = t_s + t_{ms}$$

where

- $t_s$  is the whole second part (see the Date & Time field).
- $t_{ms}$  is the microsecond part (see the Timestamp field).
- For definition of the above fields (see Section 3.1.2 Point Cloud UDP Data – Tail).

## ■ Start Time of Each Block

Given the absolute time of a Point Cloud Data Packet ( $t_0$ ), the start time of each block (i.e., the time when the first firing starts) can be calculated.

### Single Return Mode

Block	Start Time ( $\mu s$ )
Block 1	$t_0 - 9.249 - 41.666 * 2$
Block 2	$t_0 - 9.249 - 41.666$

### Dual Return Mode

Block	Start Time ( $\mu s$ )
Block 1 & Block 2	$t_0 - 9.249 - 41.666$

## ■ Firing Time Offset of Each Channel

Assume that the start time of Block  $m$  is  $T(m)$ ,  $m \in \{1, 2\}$ , then the laser firing time of Channel  $n$  in Block  $m$  is

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

The firing time offsets  $\Delta t(n)$  are in the table next page.

$\Delta t(n)$  – Firing Time Offset of Each Channel (Unit: ns)  
(continued on the next page)

Channel #	$\Delta t(n)$
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

Channel #	$\Delta t(n)$
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

Channel #	$\Delta t(n)$
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	14928

Channel #	$\Delta t(n)$
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	848

$\Delta t(n)$  – Firing Time Offset of Each Channel (Unit: ns)  
(continued)

Channel #	$\Delta t(n)$
81	13280
82	13280
83	9112
84	4976
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

Channel #	$\Delta t(n)$
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

Channel #	$\Delta t(n)$
121	8264
122	8240
123	4144
124	8264
125	8240
126	12376
127	12376
128	8264

## Appendix III 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

The angle correction file is provided when shipping the unit. In case you need to obtain the file again:

- Send a PTC command (command code: 0x05), as described in Hesai TCP API Protocol (Section 5).
- Or export the file using PandarView (see the PandarView user manual).
- Or contact a sales representative or technical support engineer from Hesai.



### Notes

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

### ■ 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 Currently 0x01



Field	Bytes	Type	Description
Protocol Version Minor	1	uint	Subclass of the point cloud UDP packet structure Currently 0x05
Channel Number	1	uint	Channel number N Always 0x80 (128 channels)
Mirror Number	1	uint	Mirror number M Always 0x03 (3 mirror surfaces)
Frame Number	1	uint	Frame number F for every 360° rotation 0x03 by default (3 frames; each mirror surface corresponds to one frame) 💡 This field is only used for PandarView display configuration, not for point cloud data analysis.
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 display configuration, not for point cloud data analysis. For example: <ul style="list-style-type: none"> <li>When F = 3 and the first 3 bytes are 0000 0001、 0000 0010、 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.</li> <li>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.</li> <li>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.</li> </ul>

Field	Bytes	Type	Description
Resolution	1	uint	Used in the units of the following fields. 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  💡 NOTE <ul style="list-style-type: none"> <li>The range of each mirror surface (End_Frame - Start_Frame) <math>\approx 120^\circ</math></li> <li>One mirror surface's End_Frame is exactly the next mirror surface's Start_Frame, and so on.</li> <li>Sum of the three mirror surface ranges = <math>360^\circ</math></li> </ul>
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, irrelevant to mirror rotation. Unit: Resolution / 25600
Azimuth_Adjust[0 : 23040-1]	23040 (128*180)	int8 array	Each channel's horizontal angle adjustments for every 2° encoder angle, relevant to mirror rotation. 2D array[128][180] <ul style="list-style-type: none"> <li>The 180 columns correspond to encoder angle positions 0°, 2°, 4°, …, and 358°.</li> <li>The 128 rows correspond to Channels 1 to 128.</li> </ul> Unit: Resolution * 0.01

Field	Bytes	Type	Description
Elevation_Adjust[0 : 23040-1]	23040 (128*180)	int8 array	<p>Each channel's vertical angle adjustments for every 2°encoder angle, relevant to mirror rotation.</p> <p>2D array[128][180]</p> <ul style="list-style-type: none"> <li>The 180 columns correspond to encoder angle positions 0°, 2°, 4°, ....., and 358°.</li> <li>The 128 rows correspond to Channels 1 to 128.</li> </ul> <p>Unit: Resolution * 0.01</p>
SHA-256 Value	32	uint	SHA-256 hash of this angle correction file

## ■ Angle Correction Calculation

### 1) Horizontal angle of the current firing channel

$$h\_angle = \left[ \frac{\alpha}{100} + \frac{\alpha_{fine}}{25600} - \frac{start\_frame(frame\_id)*resolution}{25600} \right] * 2 - \frac{\alpha_{offset}(channel\_id)*resolution}{25600} + \frac{\alpha_{adjust}(channel\_id, azimuth\_id)*resolution}{100}$$

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

### 2) Vertical angle of the current firing channel

$$v\_angle = \frac{\epsilon(channel\_id)*resolution}{25600} + \frac{\epsilon_{adjust}(channel\_id, azimuth\_id)*resolution}{100}$$

Each channel's vertical angle ( $\epsilon$ )	In the angle correction file
Each channel's vertical angle adjustments for every 2° encoder angle ( $\epsilon_{adjust}$ )	In the angle correction file

💡 If the encoder angle ( $\alpha$ ) is not divisible by 2°, the horizontal angle adjustments ( $\alpha_{adjust}$ ) and vertical angle adjustments ( $\epsilon_{adjust}$ ) should be linearly interpolated. For example:

If the  $\alpha_{adjust}$  for 50° and 52° encoder angles are a and b, respectively, then at the 51° encoder angle position,  $\alpha_{adjust} = (a + b)/2$ .

If the  $\epsilon_{adjust}$  for 50° and 52° encoder angles are c and d, respectively, then at the 50.5° encoder angle position,  $\epsilon_{adjust} = (3c + d)/4$ .

## Appendix IV Legal Notice

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