Pandar40P

40-Channel Mechanical LiDAR User Manual

HESAI Wechat

Contents

About This Manual

■ **Using This Manual**

- 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.
- This user manual does not contain information on product certifications. Please check the certification marks on the product's bottom plate and read through the corresponding certification warnings.
- 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).

■ **Access to This Manual**

To obtain the latest version:

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

■ **Technical Support**

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

service@hesaitech.com

www.hesaitech.com/en/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

■   **Special Warnings**

Laser Safety

CAUTION

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

CLASS 1 LASER PRODUCT

This product complies with IEC/EN 60825-1: 2014 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.

INVISIBLE LASER RADIATION

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. Contact information can be found in the product's user manual (refer to the *About this Manual* section).

Prohibition of Disassembly

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

■ Operating Environment

Radio Frequency Interference

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

Vibration

· If significant mechanical shocks and vibration 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±5°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, when the product is temporarily not used for measurement, the protective leather cover (supplied with the product) can be used 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 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/EN 60825-1:2014.
- 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.

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

- 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.

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.

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

The point cloud data processing features (provided on certain product models) are configurable and are intended only to assist users in extracting information from the point cloud data. Users are in full control whether to use any of these features. Moreover, users are responsible for analyzing the product's intended application scenarios and evaluating the risks of enabling one or more of these features in combination. The point cloud data processing features include but are not limited to: Noise Filtering, Interstitial Points Filtering, Retro Multi-Reflection Filtering, and Nonlinear Reflectivity Mapping.

■ Repair and Maintenance

For product repair or maintenance issues, please contact Hesai Technology or an authorized Hesai Technology service provider. Contact information can be found in the product's user manual (refer to the *About this Manual* section).

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 output format of Pandar40P.

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

Figure 1.1 Distance Measurement Using Time of Flight

1.2   Lidar Structure

40 pairs of laser emitters and receivers are attached to a motor that rotates horizontally.

Figure 1.2 Partial Cross-Sectional Diagram   Figure 1.3 Coordinate System (Isometric View)   Figure 1.4 Rotation Direction (Top View)
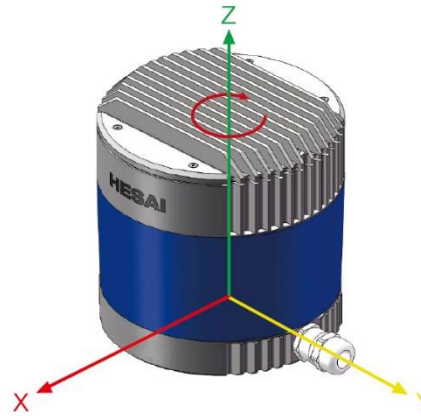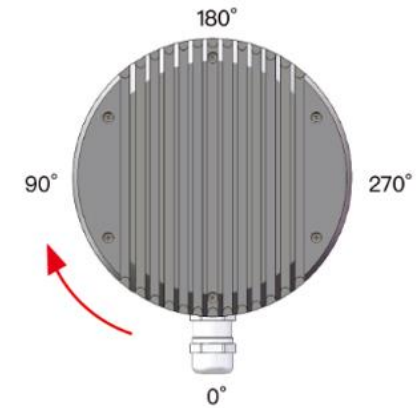
The lidar's coordinate system is illustrated in Figure 1.3. Z-axis is the axis of rotation.

The origin is shown as a red dot in Figure 1.6 on the next page. All measurements are relative to the origin.

Lidar azimuthal position is defined in Figure 1.4. Y-axis corresponds to 0°.
Each laser channel has an intrinsic azimuth offset. Channel 12 is selected to define the lidar's azimuthal position.
For example, when Channel 12 passes the 90° position:
• 	the lidar is at the 90° position;
• 	the Azimuth field in the corresponding data block in the Point Cloud Data Packet will be 90°.

1.3 Channel Distribution

The vertical resolution is
- 0.33° between Channel 6 and Channel 30
- 1° between Channel 5 and Channel 6, Channel 30 and Channel 38
- not evenly distributed in the remaining channels, as detailed in Appendix I
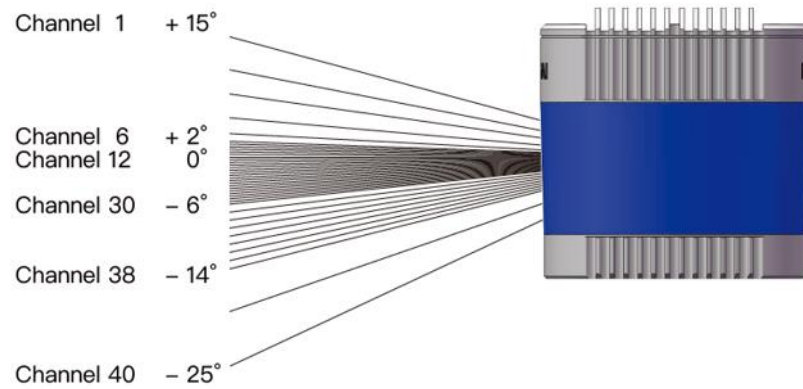
Figure 1.5 Channel Vertical Distribution
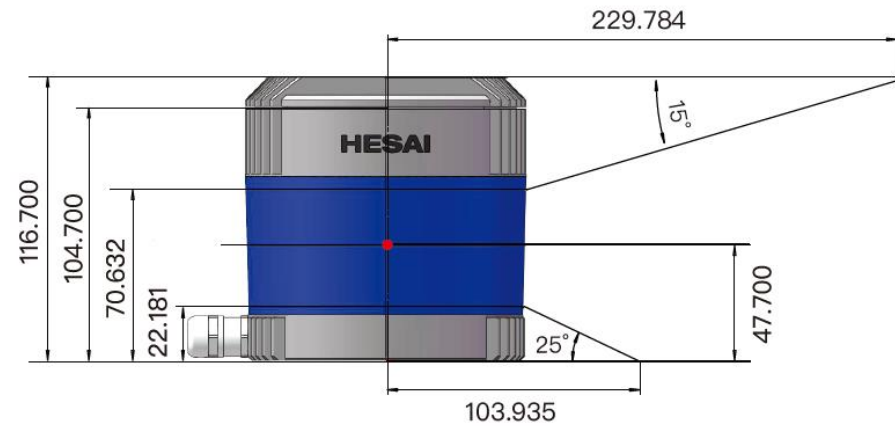
Figure 1.6 Laser Firing Position (Unit: mm)

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

The offsetted angles are recorded in this lidar unit's angle correction file, which is provided when shipping the unit.

In case you need to obtain the file again:
- Send this PTC command *PTC_COMMAND_GET_LIDAR_CALIBRATION*, as described in Hesai TCP API Protocol (Chapter 5).
- Or export the file using PandarView, see the PandarView user manual.
- Or contact a sales representative or technical support engineer from Hesai.

1.4   Specifications

SENSOR	
Scanning Method	Mechanical Rotation
Channel	40
Range Capability	0.3 to 200 m (at 10% reflectivity)
Range Accuracy ①	±5 cm (0.3 to 1 m)
	±2 cm (1 to 200 m)
FOV (Horizontal)	360°
Resolution (Horizontal)	0.2° (10 Hz), 0.4° (20 Hz)
FOV (Vertical)	40° (-25° to +15°)
Resolution (Vertical)	0.33° (-6° to +2°)
	1° (+2° to +3°, -14° to -6°)
	2° (+3° to +5°)
	3° (+5° to +11°)
	4° (+11° to +15°)
	5° (-19° to -14°)
	6° (-25° to -19°)
Frame Rate	10 Hz, 20 Hz
Returns	Single Return (Last, Strongest)
	Dual Return (Last and Strongest)

MECHANICAL/ELECTRICAL/OPERATIONAL		
Wavelength	905 nm	
Laser Class	Class 1 Eye Safe	
Ingress Protection	IP6K7	
Dimensions	Height:	116.7 mm
	Top/Bottom:	Φ118.0 / 116.0 mm
Rated Voltage Range	DC 9 to 48 V	
Power Consumption ②	18 W (typical)	
Operating Temperature	-20℃ to 65℃	
Storage Temperature	-40℃ to 85℃	
Weight	1.52 kg	

DATA I/O		
Data Transmission	UDP/IP Ethernet (100 Mbps)	
	100BASE-TX	
Measurements	Distance, Azimuth Angle, Intensity	
Data Points Generated	Single Return:	720,000 points/sec
	Dual Return:	1,440,000 points/sec
Point Cloud Data Rate	Single Return:	18.78 Mbps
	Dual Return:	37.56 Mbps
Clock Source	GPS / PTP	
PTP Clock Accuracy	≤1 μs	
PTP Clock Drift ③	≤1 μs/s	

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

① Range accuracy
- Defined as the average range error across all channels.
- May vary with range, temperature, and target reflectivity.

② Power consumption
- Not including accessories such as the connection box.
- The external power supply should be able to provide at least 18 W.

③ PTP Clock Drift
- Defined as the drift at a constant temperature after the lidar (slave clock) loses connection to the PTP master.
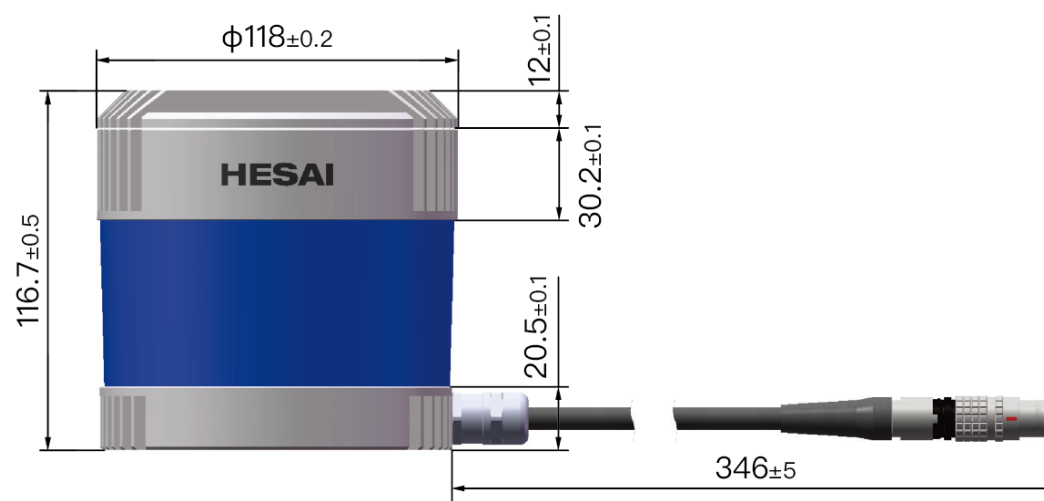
2 Setup

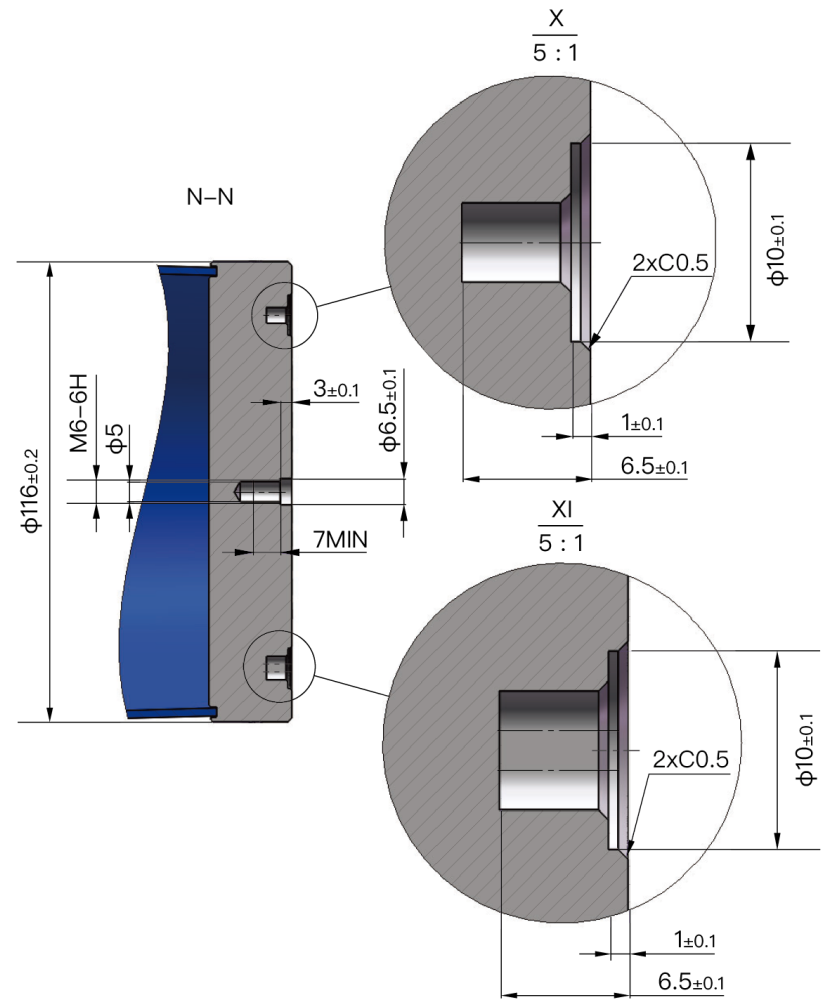## 2.1 Mechanical Installation
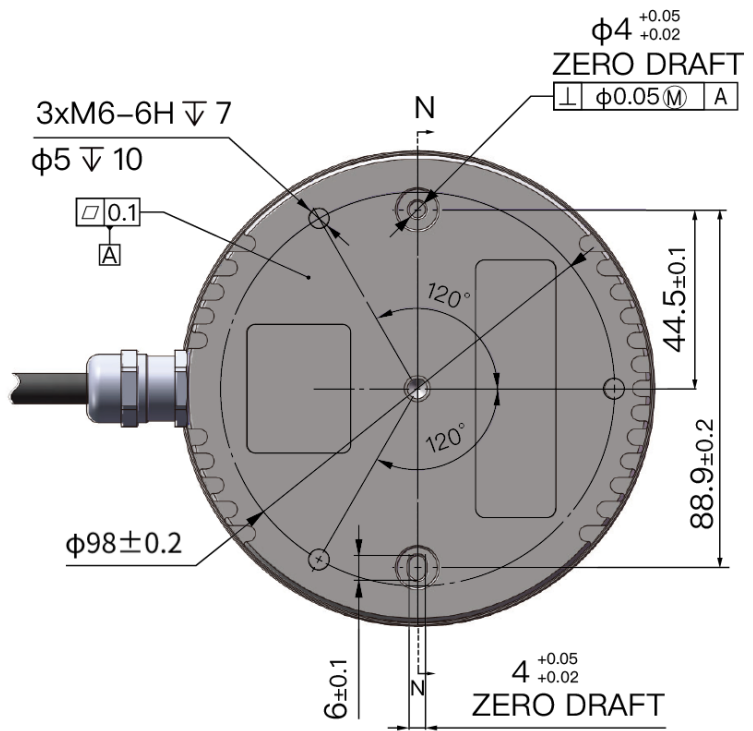

Figure 2.1 Front View (Unit: mm)

Figure 2.2 Bottom View (Unit: mm)

2.1.1　Quick Installation

M6 screw
7~9 mm exceeding the mounting plate

2xΦ4 pins
5~6 mm exceeding the mounting plate
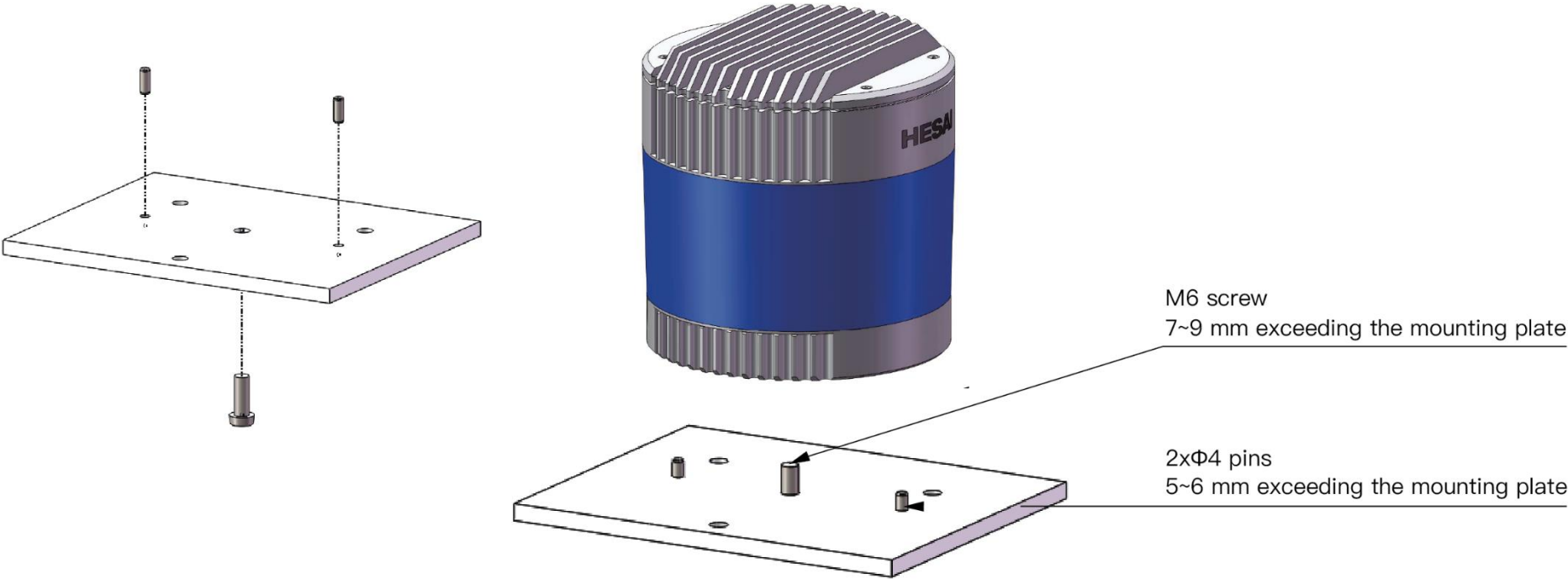
Figure 2.3 Quick Installation

2.1.2   Stable Installation

M6 screw
7~9 mm exceeding the mounting plate

3xM6 screw
5~6 mm exceeding the mounting plate

2xΦ4 pins
5~6 mm exceeding the mounting plate
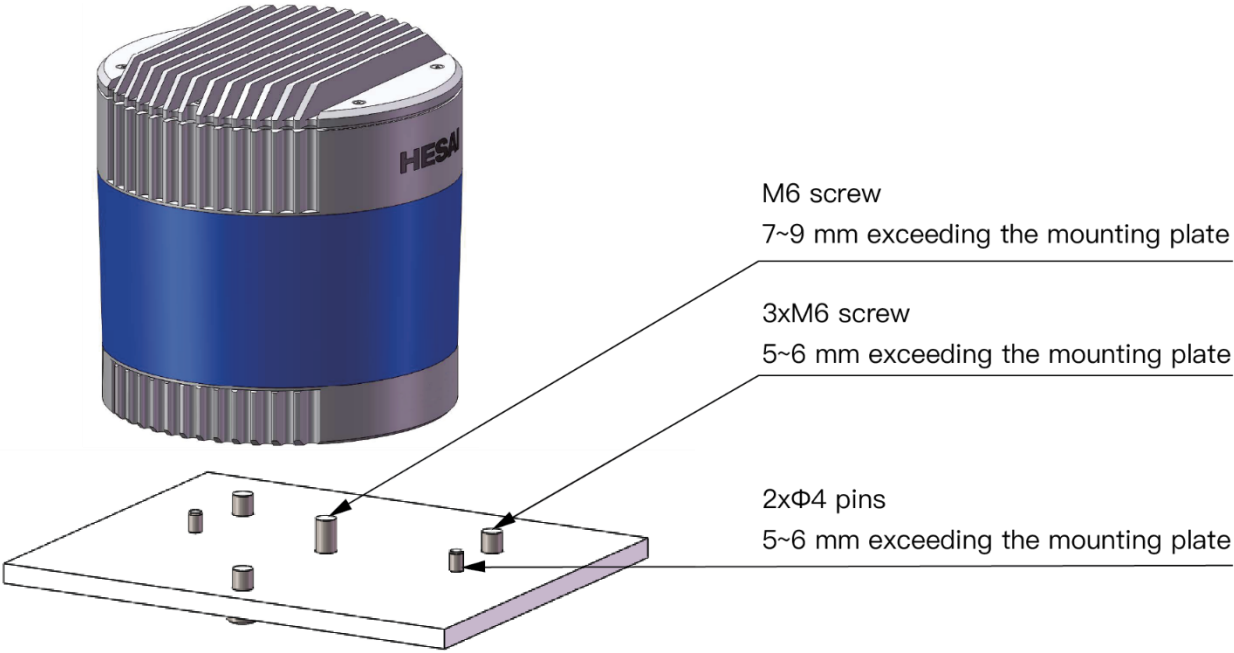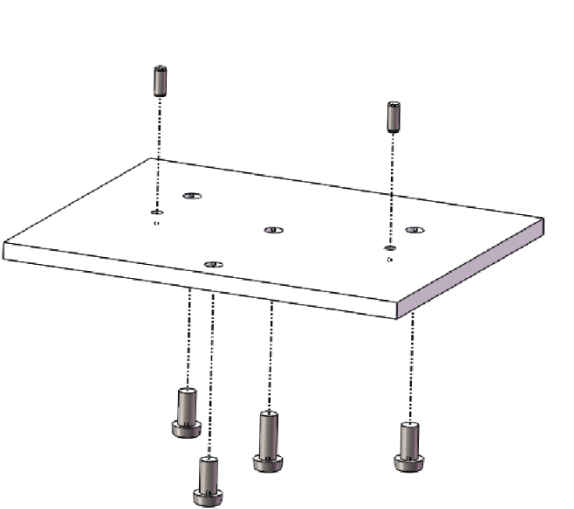
Figure 2.4 Stable Installation

2.1.3　Notes on Screw Installation

■　**Screw Type**

SEMS screws (with pre-attached flat washers and lock washers) are recommended. Property class should be at least 4.8.

■　**Threadlocker**

Before fastening a screw, apply 1 or 2 dots of threadlocker in the thread fit area. LOCTITE® 263 Threadlocker is recommended.
To ensure curing in place, wait for at least 12 hours before operating the lidar.

■　**Screw Torque**

The base material of the threaded holes is aluminum alloy instead of steel. Refer to the following table for the appropriate screw torque.

Thread Size	Recommended Screw Torque
M3	0.5 ~ 0.6 Nm
M4	1 ~ 1.5 Nm
M5	2 ~ 2.5 Nm
M6	3.5 ~ 4 Nm

■　**Thread service life**

25 times.
Each screwing counts as one time, so as each unscrewing.

2.2 Interfaces

Lemo Contact is the default communication connector. (Another option is the Phoenix Contact, detailed in the appendix)

Lemo part number: FGG.2T.316.CLAC75Z (male plug, on the lidar)
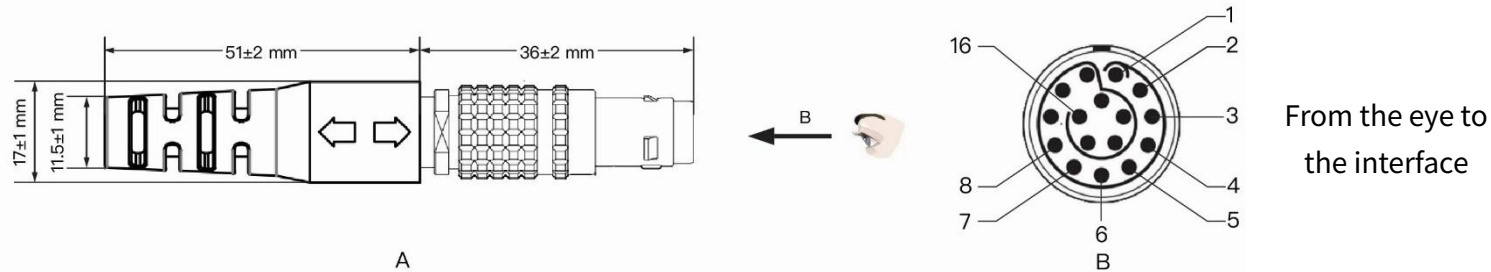

From the eye to the interface

Figure 2.5 Lemo Connector (Male Plug)

Pin #	Signal	Color	Voltage
1 ~ 4	-	-	-
5	Ethernet RX-	BLUE	-1 to 1 V
6	Ethernet RX+	BLUE/WHITE	-1 to 1 V
7	Ethernet TX-	ORANGE	-1 to 1 V
8	Ethernet TX+	ORANGE/WHITE	-1 to 1 V
9	GPS Serial Data	WHITE	-13 to +13 V
10	GPS PPS	YELLOW	TTL 3.3/5 V

Pin #	Signal	Color	Voltage
11	Power	RED	9 to 48 V
12	Power	GRAY	9 to 48 V
13	Ground (Return)	BLACK	0 V
14	Ground (Return)	GRAY/WHITE	0 V
15	-	PURPLE	-
16	-	PURPLE/WHITE	-

🔆 For the GPS PPS signal, pulse width is recommended to be over 1 ms, and the cycle is 1 s (rising edge to rising edge)

⚠ Before connecting or disconnecting an external GPS signal (either using the cable's GPS wire or via the connection box's GPS port), make sure the lidar is powered off. If the lidar has to stay powered on, make sure to:

· ground yourself in advance   · avoid touching the GPS wire or GPS port with bare hands

-☼- The timing requirements of GPS PPS and GPS Serial Data (NMEA) are shown below:

| PPS cycle	t3 = 1 s ±50 µs (rising edge to rising edge)
PPS pulse width	t1 ≥ 1 ms (10 to 100 ms recommended)
Timing relationship	NMEA signal starts after the PPS rising edge of the current second, and ends after the PPS falling edge of the current second, as shown by the gray arrows in figure above. NMEA signal ends before the PPS rising edge of the next second; t2 ≥ 100 ms.

■ **Connector Use**

Connection	Disconnection
• Turn off the power source	• Turn off the power source
• Align the red dots on the connector shells	• Pull the release sleeve on the male connector to its outermost position and hold there
• Push the plug straight into the socket	• Pull the plug from the socket

⚠ **Warnings**

• DO NOT attempt to force open a connection by pulling on the cables or the shells, 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.

Before connection: align the red dots
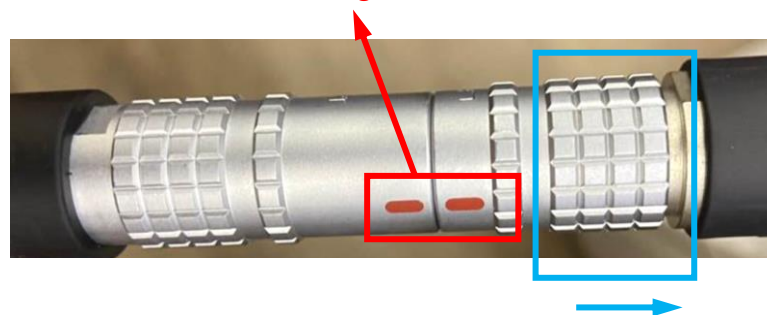
Before disconnection: pull the release sleeve to its outermost position and hold there

Figure 2.6 Lemo Connection/Disconnection

■ **Cables**

OD (outside diameter) = 7.50±0.30 mm

Minimum bend radius: 7.5 * OD

⚠ To avoid damaging the cable, do not bend the cable at the cable gland.

2.3　Connection Box (Optional)

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

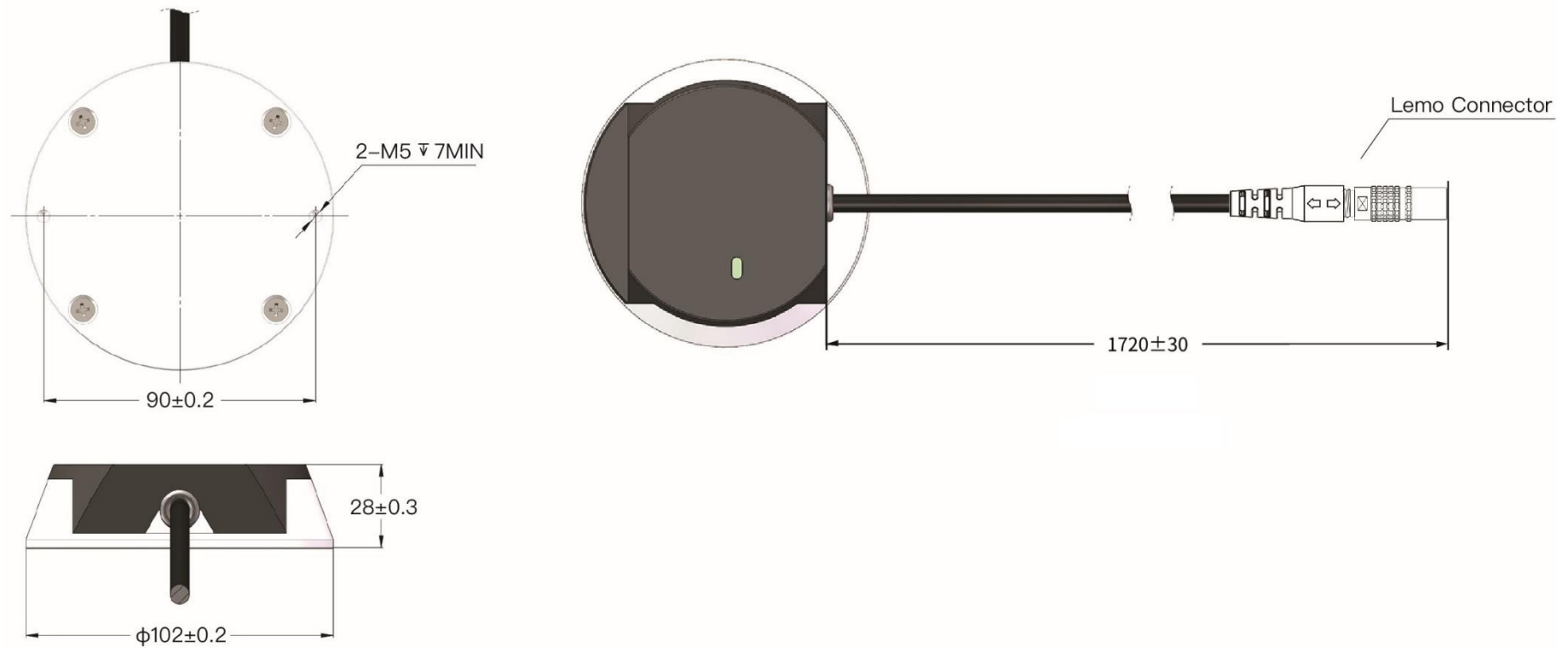Lemo part number: PHG.2T.316.CLLC75Z (female socket, on the connection box)

Figure 2.7 Connection Box (Unit: mm)
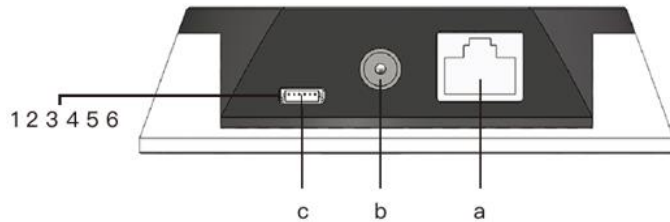
2.3.1 Connection Box Interfaces
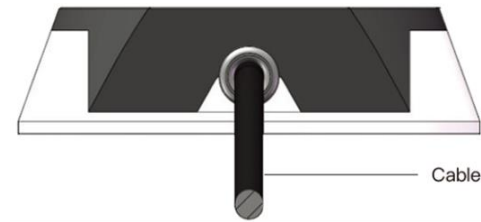

Figure 2.8 Connection Box (Front)

Figure 2.9 Connection Box (Back)

Port #	Port Name	Description
a	Standard Ethernet Port	RJ45, 100 Mbps Ethernet
b	Power Port	Use DC-005 DC power adapter
c	GPS Port	Connector part number: JST SM06B-SRSS-TB
		Recommended connector for the external GPS module: JST SHR-06V-S-B
		Voltage standard: RS232　　　　Baud rate: 9600 bps

The GPS port pin numbers are 1 to 6 from left to right, defined as follows:

Pin #	Direction	Pin Description	Requirements
1	Input	PPS (pulse-per-second) signal for synchronization	TTL level 3.3/5 V　　　Recommended pulse width: ≥1 ms Cycle: 1 s (from rising edge to rising edge)
2	Output	Power for the external GPS module	5 V
3	Output	Ground for the external GPS module	-
4	Input	Receiving serial data from the external GPS module	RS232 level
5	Output	Ground for the external GPS module	-
6	-	Reserved	-

2.3.2   Connection

Connect the power port to the adapter

GPS Module
(third party)

Power port and standard
Ethernet port

LiDAR

HESAI

Connect the Ethernet port to
a computer.

Connection Box

Computer

Figure 2.10 Connection Box (Connection with GPS)

Connect the power port to the adapter.

Power port and standard Ethernet port
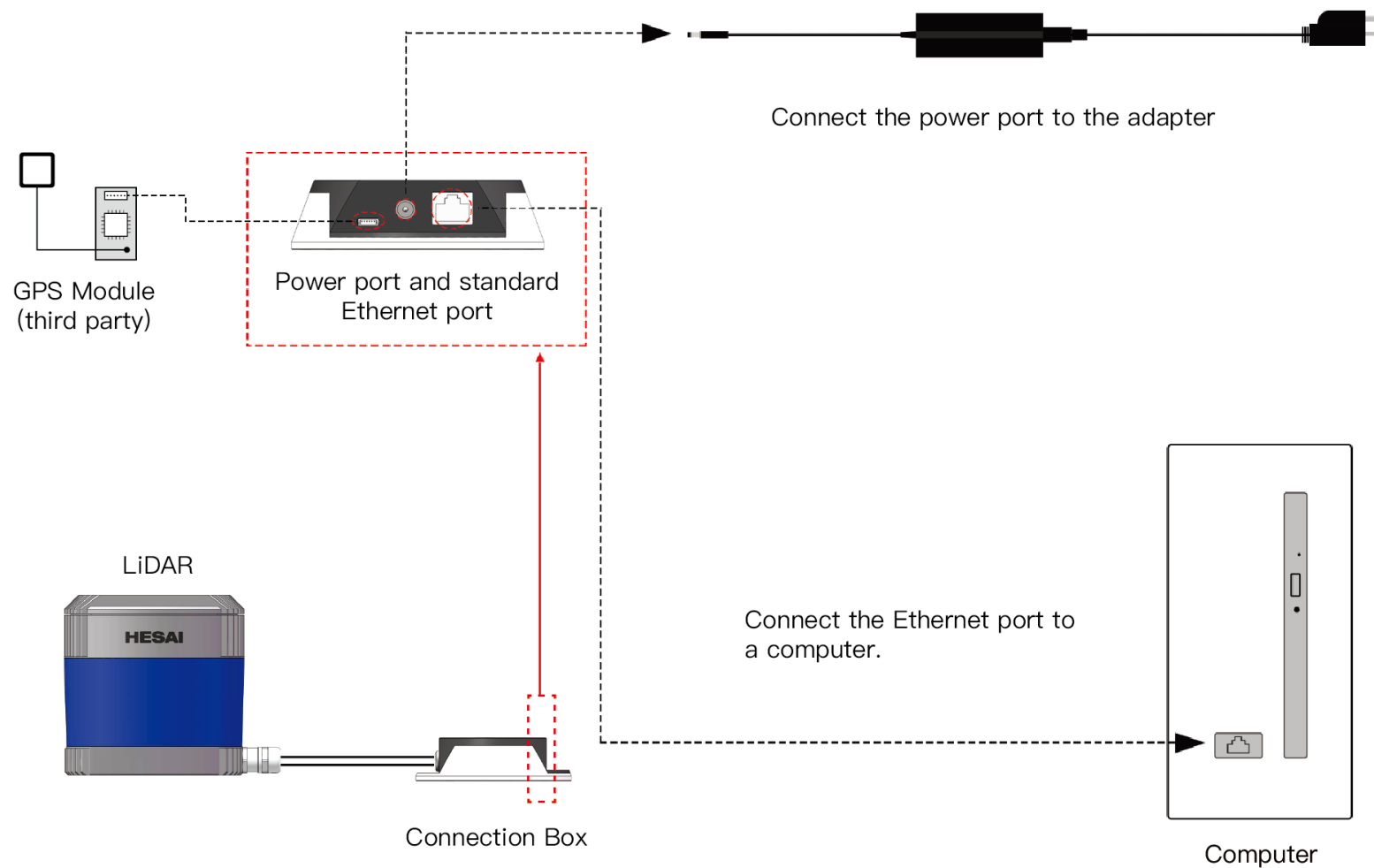
PTP Master (third party)

LiDAR

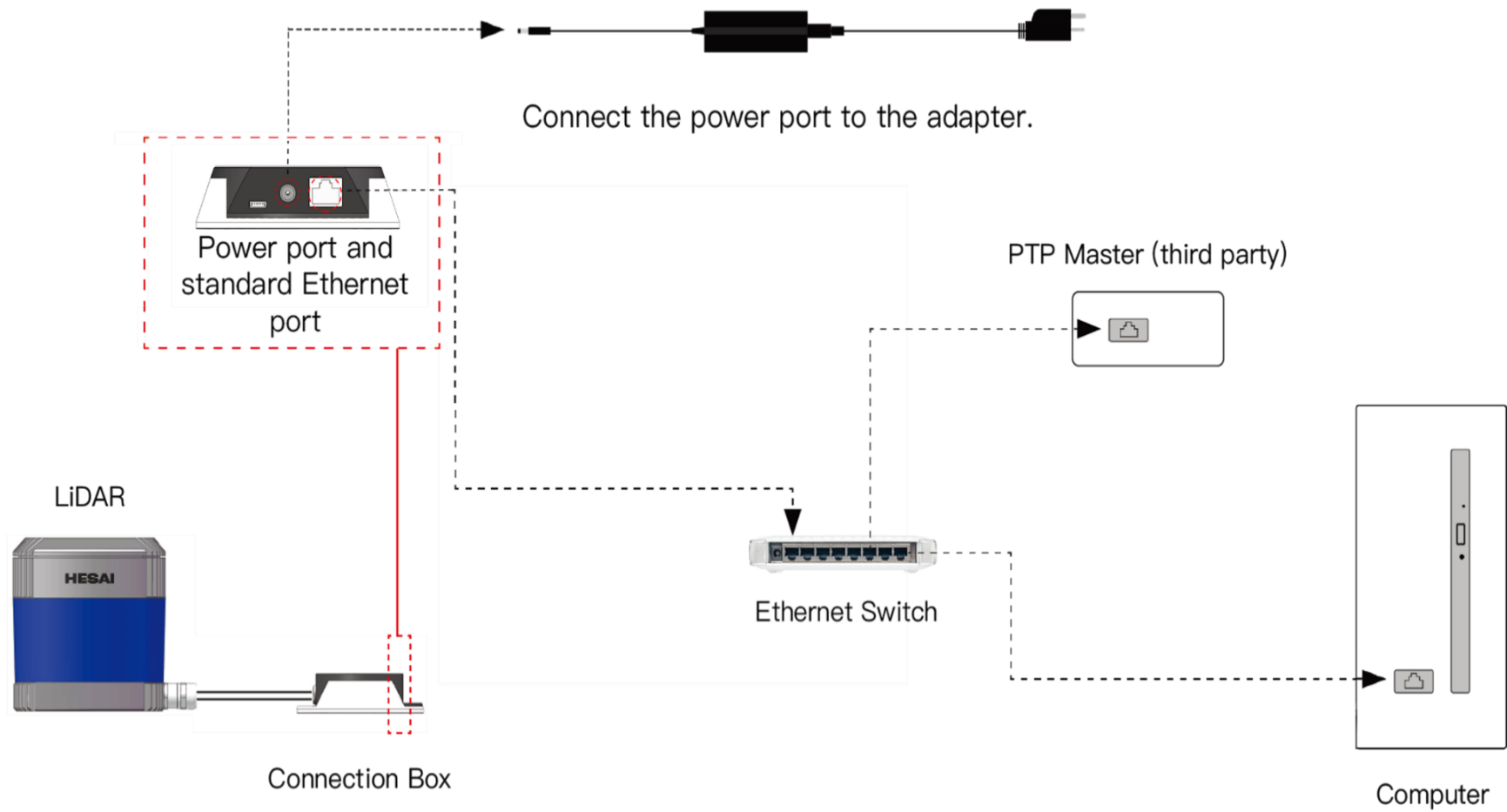HESAI

Ethernet Switch

Connection Box

Computer

Figure 2.11 Connection Box (Connection with PTP)

2.4 Get Ready to Use

Before operating the lidar, strip away the protective cover outside the cover lens.

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, see PandarView User Manual.

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

To obtain the SDKs (Software Development Kits) for your product model,
- please find the download link at: www.hesaitech.com/en/download (Product Documentation → select product model)
- or visit Hesai's official GitHub page: https://github.com/HesaiTechnology

3 Data Structure

The lidar outputs Point Cloud Data Packets and GPS Data Packets using 100 Mbps Ethernet UDP/IP.

Unless otherwise specified, all the multi-byte fields are unsigned values in little endian format.
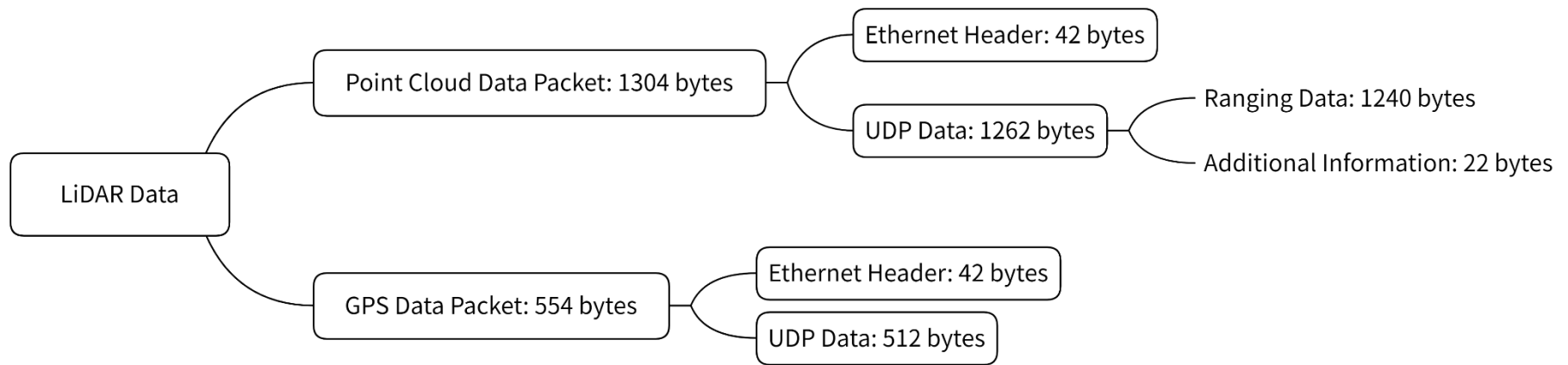
Figure 3.1 Data Structure with UDP Sequence OFF

UDP sequence is OFF by default. When UDP sequence is ON, the Additional Information in the UDP data changes from 22 bytes to 26 bytes.

3.1 Point Cloud Data Packet

3.1.1 Ethernet Header

Each lidar has a unique MAC address. The source IP is 192.168.1.201 by default, and the destination IP is 255.255.255.255 (broadcast).

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, representing 10000)　　　Destination port (0x0940, representing 2368)
UDP Length	2	0x04F6 when UDP sequence is OFF, representing 1270 bytes (8 bytes more than the size of the Point Cloud UDP Data, shown in Figure 3.1) 0x04FA when UDP sequence is ON, representing 1274 bytes
UDP Checksum	2	Shown in the figure below

Figure 3.2 Point Cloud Ethernet Header - Internet Protocol

3.1.2   UDP Data

■   Ranging Data: 1240 bytes (10 blocks)

Block 1	Block 2	Block 3	...	Block 10
0xFFEE	0xFFEE	0xFFEE	...	0xFFEE
Azimuth 1	Azimuth 2	Azimuth 3	...	Azimuth 10
Channel 1	Channel 1	Channel 1	...	Channel 1
Channel 2	Channel 2	Channel 2	...	Channel 2
...	...	...	...	...
Channel 40	Channel 40	Channel 40	...	Channel 40

Block size = 2 + size of Azimuth + 40* size of Channel X

Each block in the Ranging Data: 124 bytes			
Field	Bytes	Description	
0xFFEE	2	Header, meaningless, 0xFF first	
Azimuth	2	Current reference angle of the rotor Unit: 0.01°	
Channel X	3	2-byte Distance	Distance Value = Distance * 4 mm
		1-byte Reflectivity	Range: 0 to 255 The mapping from this field to target reflectivity can be selected in Section 4.2 (Web Control – Settings)

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 changes every two blocks

■ Additional Information: 22/26 bytes when UDP sequence is OFF/ON

Field	Bytes	Description
Reserved	5	-
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	2	-
Motor Speed	2	Unit: RPM
Timestamp	4	The "μs time" part of the absolute time of this data packet (defined in Appendix II), in units of 1 μs Range: 0 to 1000000 μs (1 s)
Return Mode	1	0x37 for Strongest Return mode 0x38 for Last Return mode 0x39 for Dual Return mode (Last, Strongest)
Factory Information	1	0x42 (or 0x43)
Date & Time	6	The absolute UTC time of this data packet, accurate to the second. | Each Byte	Range (Decimal)
---	---
Year (current year minus 2000)	Positive integers
Month	1 to 12
Day	1 to 31
Hour	0 to 23
Minute	0 to 59
Second	0 to 59	

Field	Bytes	Description
UDP Sequence	4	Added only when UDP sequence is ON
		Label the sequence number of Point Cloud UDP packets
		0 to 0xFF FF FF FF

3.1.3　Point Cloud Data Analysis

Take Channel 5 in Block 3 as an example:

■　**Analyze the vertical angle of a data point**

The designed vertical angle of Channel 5 is 3.00°, according to Appendix I (Channel Distribution)

☼　Notes
- The accurate vertical angle is recorded in this LiDAR's unit's angle correction file, see Section 1.3 (Channel Distribution).
- 0° is the horizontal direction; define upward as positive (see Figure 1.5).
- Channel # counts from 1, top to bottom.

■　**Analyze the horizontal angle of a data point**

☼　Y-axis is the 0° position; define clockwise in the top view as positive (see Figure 1.4).

Horizontal angle = ① + ② + ③

①　Rotor reference angle during the current round of firing
In the Azimuth field of Block 3.

②　Horizontal angle offset of the channel
The designed offset for Channel 5 is -1.042°, according to Appendix I (Channel Distribution Table).
☼　The accurate horizontal angle offset is recorded in this LiDAR's unit's angle correction file, see Section 1.3 (Channel Distribution).

③　Firing time angular offset of the channel = ④ * ⑤

④   Firing time offset of the channel

Look up the table in Appendix II (Absolute Time of Point Cloud Data).

⑤   Spin rate of the motor

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 3
· Distance Unit: 4 mm

■   **Draw the data point in a polar or rectangular coordinate system**
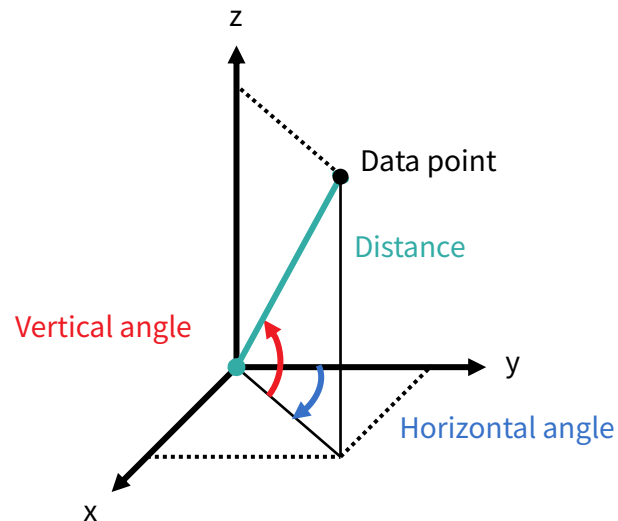
■   **Obtain the real-time point cloud data by analyzing and drawing every data point in each frame**

3.2   GPS Data Packet

When GPS is selected as the clock source (see Section 4.2 Web Control - Settings), GPS Data Packets are triggered every second. When PTP is selected as the clock source, the LiDAR does not output GPS Data Packet.

All the multi-byte values are unsigned and in little endian format.

3.2.1   Ethernet Header

The source IP is 192.168.1.201 by default.

The destination IP address is 255.255.255.255 and in broadcast form.

GPS 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, represents 10000)
		Destination port (0x277E, represents 10110)
UDP Length	2	0x208, representing 520 bytes (8 bytes more than the size of the GPS UDP Data, shown in Figure 3.1)
UDP Checksum	2	-

```
⊟ Internet Protocol, Src: 192.168.1.201 (192.168.1.201), Dst: 255.255.255.255 (255.255.255.255)
     Version: 4
     Header length: 20 bytes
  ⊞ Differentiated Services Field: 0x00 (DSCP 0x00: Default; ECN: 0x00)
     Total Length: 540
     Identification: 0x1841 (6209)
  ⊞ Flags: 0x02 (Don't Fragment)
     Fragment offset: 0
     Time to live: 64
     Protocol: UDP (17)
  ⊞ Header checksum: 0x5e1f [correct]
     Source: 192.168.1.201 (192.168.1.201)
     Destination: 255.255.255.255 (255.255.255.255)
```

Figure 3.3 GPS Ethernet Header - Internet Protocol

3.2.2   UDP Data

GPS UDP data: 512 bytes				
Field	Bytes	Description		
GPS Time Data	18	Header	2 bytes	0xFFEE (0xFF first)
		Date	6 bytes	Year, month, and day (2 bytes each, lower byte first) in ASCII
		Time	6 bytes	Second, minute, and hour (2 bytes each, lower byte first) in ASCII
		Reserved	4 bytes	-
GPRMC/GPGGA Data	84	NMEA sentence that contains date and time ASCII code, valid till 2 bytes after the asterisk (*) The lidar can receive either GPRMC or GPGGA, see Chapter 4 (Web Control - Settings)		
Reserved	404	404 bytes of 0xDF		
GPS Positioning Status	1	ASCII code, obtained from $GPRMC or $GPGGA <table><tr><td>When $GPRMC is selected:</td><td>When $GPGGA is selected:</td></tr><tr><td>Output A, V, or NUL · A (hex = 41) = Active · V (hex = 56) = Void · NUL (hex = 0) = GPS being unlocked</td><td>Output 0 to 9, as defined by the GPS device manufacturer. Commonly used definitions: · 0 = invalid · 1 = GPS fix (SPS) · 2 = DGPS fix · 4 = RTK fixed · 5 = RTK float · 6 = estimated (dead reckoning)</td></tr></table>		
PPS Lock Flag	1	1 - locked 0 - unlocked		
Reserved	4	-		

■   **GPRMC Data Format**

$GPRMC, <01>, <02>, <03>, <04>, <05>, <06>, <07>, <08>, <09>, <10>, <11>, <12>*hh

Field #	Field	Description
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format
<02>	Location Status	A (hex = 41) for Valid Position V (hex = 56) for Invalid Position NUL (hex = 0) for GPS being unlocked
…		
<09>	UTC Date	Date information Typically in ddmmyy (day, month, year) format
…		

The lidar's GPS data interface is compatible with a variety of GPRMC formats, as long as:

<01> is the hour, minute, and second information
<09> is the date information.

For example, the following two formats are both acceptable:

```
$GPRMC,072242,A,3027.3680,N,11423.6975,E,000.0,316.7,160617,004.1,W*67
$GPRMC,065829.00,A,3121.86377,N,12114.68322,E,0.027,,160617,,,A*74
```

■ **GPGGA Data Format**

$GPGGA, <01>, <02>, <03>, <04>, <05>, <06>, <07>, <08>, <09>, <10>, <11>, <12>*hh

Field #	Field	Description
<01>	UTC Time	Hour, minute, and second Typically in hhmmss (hour, minute, second) format
...		
<06>	GPS Fix Quality	0 = invalid 1 = GPS fix (SPS) 2 = DGPS fix 3 = PPS fix 6 = estimated (dead reckoning)
...		

The lidar's GPS data interface is compatible with a variety of GPGGA formats, as long as:

<01> is the hour, minute, and second information

For example, the following two formats are both acceptable:

$GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47
$GPGGA,134658.00,5106.9792,N,11402.3003,W,2,09,1.0,1048.47,M,-6.27,M,08,AAAA*60

3.2.3   GPS Data Analysis

Figure 3.4 GPS Data Packet - UDP Data (Example)

Date

Field	Data (ASCII Code)	Characters	Meaning
Year	0x30 0x32	'0', '2'	20
Month	0x34 0x30	'4', '0'	04
Day	0x37 0x30	'7', '0'	07

Time

Field	Data (ASCII Code)	Characters	Meaning
Second	0x38 0x35	'8', '5'	58
Minute	0x37 0x30	'7', '0'	07
Hour	0x34 0x30	'4', '0'	04

μs Time

4 bytes, in units of μs, using the same clock source as the GPS Timestamp in Point Cloud Data Packets

Reset to 0 at the rising edge of each PPS signal

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	600 rpm
GPS	Unlock
NMEA (GPRMC/GPGGA)	Unlock
PTP	Free Run

Device Info   Device Log

Model	Pandar40P.
S/N	PA64XXXXXXXXXXXXXX
MAC Address	XX:XX:XX:XX:XX:XX
Software Version	2.10.8
Sensor Firmware Version	4.3.44a
Controller Firmware Version	4.53

Button	Description
Device Log	Click to download a .JSON file that contains the lidar status, device info, all configurable parameters, and the upgrade log.

Parameter	Description
Spin Rate	Spin Rate of the motor (RPM) = frame rate (Hz) * 60
GPS	GPS (PPS) status | Lock	Lidar's internal clock is in sync with GPS
Unlock	Not in sync	
NMEA (GPRMC/GPGGA)	NMEA status | Lock	After receiving a valid NMEA message
Unlock	Not receiving a valid NMEA message for over 2 s	
PTP	PTP status | 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.	

4.2   Settings

<div>

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
Spin Rate		600 rpm
Return Mode		Dual Return
Sync Angle	☐	0
Trigger Method		Time Based
Clock Source		GPS
GPS Mode		GPRMC
GPS Destination Port		10110

</div>

(Continued on the next page)

(Continued)

Noise Filtering   OFF

Interstitial Points Filtering   OFF

Retro Multi-Reflection Filtering   OFF

Reflectivity Mapping   Linear Mapping

Standby Mode   In Operation / Standby

Save

Button	Description
Reset All Settings	Reset all the configurable parameters to factory defaults, including: ・ Section 4.2 (Settings) ・ Section 4.3 (Azimuth FOV)
Save	Save and execute all the settings on this page. ・ Exception: Standby Mode takes effect immediately.

4.2.1   Network Settings

Parameter	Options	Description
VLAN	Default: OFF VLAN ID: 1 ~ 4094	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). 🔆 **Notes** ・ Once configured, the VLAN ID does not change during firmware upgrades. ・ When VLAN is enabled, PTP connection will be lost; when VLAN is disabled, PTP connection will automatically recover. ⚠️ **Warnings** If the lidar's VLAN ID differs from the receiving host's, users will lose access to web control. To minimize such risks, the VLAN ID is zero (invalid value) by default. ・ When checking the checkbox, users will be alerted to input a valid VLAN ID. ・ When unchecking the checkbox, the VLAN ID will default to zero.
Destination IP	Any address except for 0.0.0.0, 127.0.0.1, and the lidar's IP. Default: 255.255.255.255	<table><tr><td>Mode</td><td>Destination IP</td></tr><tr><td>Broadcast (default)</td><td>255.255.255.255</td></tr><tr><td>Multicast</td><td>User-defined</td></tr><tr><td>Unicast</td><td>Same as the PC's IP address</td></tr></table>

4.2.2 Function Settings

Parameter	Options	Description
Spin Rate	600 RPM (default) 1200 RPM	The setting spin rate is also shown on web control, see Section 4.1 (Web Control – Home).
Return Mode	Single Return • Last / Strongest	Also shown in Point Cloud Data Packets, see the Return Mode field in Section 3.1.2 (Point Cloud UDP Data).
Sync Angle	0° to 360°	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 (Lidar Structure). Definition of full second • When GPS is locked: the rising edge of the GPS PPS signal • When PTP is tracking or locked: retrieved from the PTP master clock • When neither GPS nor PTP is locked: the rising edge of the lidar's internal 1 Hz signal • Detailed in Appendix II (Absolute Time of Point Cloud Data) To phase-lock multiple lidars • Connect the lidars to the same clock source and set the same sync angle, and these lidars will rotate to that same azimuthal position at every full second.

Parameter	Options	Description
Trigger Method	Time-Based (default) Angle-Based	The way laser firings are triggered. 	Angle-based	Lasers fire every 0.2° at 10 Hz or 0.4° at 20 Hz.
Time-based	Lasers fire every 55.56 us.	
Noise Filtering	OFF (default) ON	To mitigate the scattered false positives (i.e. noise points) in point cloud data.
Interstitial Points Filtering	OFF (default) ON	To mitigate the interstitial points. Definition of interstitial points: when a beam partially hits on a front target's edge and further hits on a rear target, the return signal can result in a false point located between both targets.
Retro Multi-Reflection Filtering	OFF (default) ON	To mitigate the false positives at twice the distance of a retroflector.
Reflectivity Mapping	Linear (default) Nonlinear Mapping 1#/2#		Linear	The Reflectivity field in Point Cloud Data Packets linearly represents target reflectivity (0 ~ 255%).
Nonlinear 1# and 2#	Increases the contrast in low-reflectivity regions, see Appendix IV (Nonlinear Reflectivity Mapping).	
Standby Mode	In Operation (default) Standby	In Standby mode, the motor stops running and lasers stop firing.

4.2.3　Time Settings

```
Clock Source                                GPS
    GPS Mode                                GPRMC
    GPS Destination Port                    10110
```

```
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	GPS (default) PTP	External source of absolute time

■ With GPS Selected

Parameter	Options	Description
GPS Mode	GPRMC (default) GPGGA	Format of the NMEA data received from the external GPS module, see Section 3.2.2 (GPS UDP Data)
GPS Baud Rate	9600 19200 38400 115200	
Destination Port	Default: 10110	Port used for sending GPS Data packets

■ With PTP Selected

The lidar does not output GPS Data Packets.

Parameter	Options	Description
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	Netword 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>
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)

When using the 802.1AS or 802.1AS Automotive profile:

Parameter	Options	Description
Switch Type	TSN (default) Non-TSN	<table><tr><td>TSN</td><td>Time Sensitive Network, using Peer-to-Peer delay mechanism</td></tr><tr><td>Non-TSN</td><td>Using End-to-End delay mechanism</td></tr></table>

4.3   Azimuth FOV

Button	Description
Save	Save and execute all the settings on this page.

Parameter	Options	Description
Azimuth FOV Setting	For all channels (default) Multi-section FOV	Configuration mode of the azimuth FOV. The lidar outputs valid data only within the specified azimuth FOV ranges.

☼ **Note**

· The angles in degrees are accurate to the first decimal place.

· If the Start Angle is larger than the End Angle, then the actual range is the union of [Start Angle, 360°] and [0°, End Angle].

　○ For instance, when the angle range is set to be [270°, 90°], the actual azimuth FOV is [270°, 360°]∪[0°, 90°].

4.3.1   For all channels

Input a Start Angle and an End Angle to form a continuous angle range.
This range applies to all channels.

4.3.2　For each channel

Users can configure one continuous angle range for each channel.
Each channel outputs valid data only within its specified range.

The "Status" button for each channel is gray by default, indicating that the angle range is [0°, 360°].
To activate the angle range configuration for each channel, click the corresponding button to make it green.

Click the "Enable/Disable All" button to activate/deactivate the angle range configuration for all channels.

Azimuth FOV Setting		For each channel ▼	

Enable/Disable All

Status	Channel	Start Angle	End Angle
●	1	0.0	0.0
●	2	0.0	0.0
●	3	0.0	0.0

Save

4.3.3   Multi-section FOV

Users can configure up to ten continuous angle ranges (i.e. sections) for each channel.
Each channel outputs valid data only within its specified ranges.

The "Status" button for each channel is gray by default, indicating that the angle range is [0°, 360°].
To activate the angle range configuration for each channel, click the corresponding button to make it green.

Click the "Enable/Disable All" button to activate/deactivate the angle range configuration for all channels.

4.4   Operation Statistics

These operating parameters are shown in real time:

Start-Up Counts	510
Internal Temperature	32.10℃
System Uptime	0 h 5 min
Total Operation Time	559 h 43 min

Internal Temperature	Operation Time
< -40 ℃	0 h 1 min
-40 to -20 ℃	0 h 46 min
...	...
100 to 120 ℃	1 h 44 min
>120 ℃	0 h 0 min

4.5 Upgrade

Preparation
- Please contact Hesai technical support to receive encrypted and signed upgrade files.
- During the upgrade, it is recommended to place a protective leather 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
Software Version	2.10.8
Firmware of Sensor Version	4.3.44a
Firmware of Controller Version	4.53
Upgrade Log	-

5 Communication Protocol

To receive Hesai lidar's PTC (Pandar TCP Commands) and HTTP API Protocols, 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	99% isopropyl alcohol (IPA)
	or 99% ethanol (absolute alcohol)
	or distilled water
	⚠ When using IPA or alcohol, please ensure adequate ventilation and keep away from fire.
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 curved 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	Verify that • power adapter is properly connected and in good condition • connection box is intact • input voltage and current satisfy the requirements in Section 2.3 (Connection Box) Power on again to check if the symptom persists.
Motor is not running	Verify that • power adapter is properly connected and in good condition • if a connection box is used, the connection box is intact • input voltage and current satisfy the requirements in Section 1.4 (Specifications) and 2.3 (Connection Box) • web control can be accessed (see "cannot open web control" on the next page) Power on again to check if the symptom persists.

Symptoms	Points to Check
Motor is running but no output data is received, neither on Wireshark nor on PandarView	Verify that · Ethernet cable is properly connected (by unplugging and plugging again) · Lidar's Destination IP is correctly set on the Settings page of web control · horizontal FOV is properly set on the Azimuth FOV page of web control · firmware version of the sensor is correctly shown on the Upgrade page of web control · 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 Power on again to check if the symptom persists.
Can receive data on Wireshark but not on PandarView	Verify that: · the Lidar Destination Port is set correctly on the Settings page of web control · PC's firewall is disabled, or that PandarView is added to the firewall exceptions · if VLAN is enabled, the PC's VLAN ID is the same with the lidar's · the latest PandarView version (see the Download page of Hesai's official website or contact Hesai technical support) is installed on the PC Power on again to check if the symptom persists.

Symptoms	Points to Check
Cannot open web control	Verify that • Ethernet cable is properly connected (by unplugging and plugging again) • 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 • if VLAN is enabled, the PC's VLAN ID is the same with the lidar's Afterwards, • restart PC, or connect the lidar to another PC • power on again to check if the symptom persists
Abnormal packet size (missing packets)	Verify that • horizontal FOV is properly set on the Azimuth FOV page of web control • motor's spin rate is steady on the Home page of web control • Lidar's internal temperature is between -20℃ and 95℃ on the Operation Statistics page of web control • Ethernet is not overloaded • no switch is connected into the network. The data transmitted from other devices may cause network congestion and packet loss Afterwards, • connect the PC only to the lidar and check for packet loss • power on again to check if the symptom persists

Symptoms	Points to Check
Abnormal point cloud (obviously misaligned points, flashing points, or incomplete FOV)	Verify that · Lidar's cover lens is clean. If not, refer to Chapter 6 (Sensor Maintenance) for the cleaning method · Lidar's calibration file is imported, see *PandarView User Manual* (Use) · horizontal FOV is properly set on the Azimuth FOV page of web control · motor's spin rate is steady on the Home page of web control · Lidar's internal temperature is between -20°C and 95°C on the Operation Statistics page of web control Afterwards, check for packet loss · 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 If the point cloud is still abnormal · Try connecting the lidar to another PC · Power on again to check if the symptom persists
GPS cannot be locked	Verify that · GPS receiver is properly connected · PPS signal is connected to the lidar · Destination GPS Port is correct on the Settings page of web control · input GPS signals satisfy the electrical requirements in Section 2.2 (Interface) and Section 2.3.1 (Connection Box) Power on again to check if the symptom persists

Appendix I   Channel Distribution

The Horizontal Angle (Azimuth) Offsets and Vertical Angles (Elevation) in the table next page are design values.
The accurate values are in this lidar's unit's angle correction file, see Section 1.3 (Channel Distribution) and Section 3.1.3 (Point Cloud Data Analysis).

Channel Distribution (To Be Continued)

Channel # in UDP Data	Horizontal Angle Offset (Azimuth)	Vertical Angle (Elevation)	Instrument Range (in meters)	Range (in meters) with Reflectivity
01 (Top Beam)	-1.042°	15.00°	130	200@20%
02	-1.042°	11.00°	130	200@20%
03	-1.042°	8.00°	130	200@20%
04	-1.042°	5.00°	130	200@20%
05	-1.042°	3.00°	230	200@20%
06	-1.042°	2.00°	230	200@20%
07	3.125°	1.67°	230	200@20%
08	-5.208°	1.33°	230	200@20%
09	-1.042°	1.00°	230	200@10%
10	3.125°	0.67°	230	200@10%
11	-5.208°	0.33°	230	200@10%
12 (Horizontal Beam)	-1.042°	0.00°	230	200@10%
13	3.125°	-0.33°	230	200@10%
14	-5.208°	-0.67°	230	200@10%
15	-1.042°	-1.00°	230	200@10%
16	3.125°	-1.33°	230	200@10%
17	-5.208°	-1.67°	230	200@10%
18	-1.042°	-2.00°	230	200@10%
19	3.125°	-2.33°	230	200@20%
20	-5.208°	-2.67°	230	200@20%

Channel Distribution (Continued)

Channel # in UDP Data	Horizontal Angle Offset (Azimuth)	Vertical Angle (Elevation)	Instrument Range (in meters)	Range (in meters) with Reflectivity
21	-1.042°	-3.00°	230	200@20%
22	3.125°	-3.33°	230	200@20%
23	-5.208°	-3.67°	230	200@20%
24	-1.042°	-4.00°	230	200@20%
25	3.125°	-4.33°	130	200@20%
26	-5.208°	-4.67°	130	200@20%
27	-1.042°	-5.00°	130	200@20%
28	3.125°	-5.33°	130	200@20%
29	-5.208°	-5.67°	130	200@20%
30	-1.042°	-6.00°	130	200@20%
31	-1.042°	-7.00°	130	200@20%
32	-1.042°	-8.00°	130	200@20%
33	-1.042°	-9.00°	130	200@20%
34	-1.042°	-10.00°	130	200@20%
35	-1.042°	-11.00°	130	200@20%
36	-1.042°	-12.00°	130	200@20%
37	-1.042°	-13.00°	130	200@20%
38	-1.042°	-14.00°	130	200@20%
39	-1.042°	-19.00°	130	200@20%
40 (Bottom Beam)	-1.042°	-25.00°	130	200@20%

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 (GPS/PTP).
Users can select the clock source, see Section 4.2 (Web Control - Settings).

1) GPS as the Clock Source

- The lidar connects to a third-party GPS module to obtain the PPS (pulse-per-second) signal and the NMEA sentence ($GPRMC or $GPGGA).
- Users may select either $GPRMC or $GPGGA sentences, see Section 4.2 (Web Control – Settings).
- Users may check the signal status of GPS PPS and NMEA, see Section 4.1 (Web Control - Home).
- The timing requirements of PPS and NMEA are shown in Section 2.2.1 (Pin Description).
- Each rising edge of the lidar's internal 1 Hz signal triggers a GPS Data Packet. The data format is detailed in Section 3.2 (GPS Data Packet).

The absolute time is updated as follows.

NMEA status	Date & Time (accurate to the second)	Lidar behavior
Unlocked	Virtual	Starts counting from a virtual UTC time (such as 2000-01-01 00:00:00) using the lidar's internal 1 Hz signal.
Locked	Synchronized	At each rising edge of the internal 1 Hz signal, obtain the actual date and time by • extracting the date and time from the previous NMEA message, and • automatically adding 1 full second.
Lost	Drifting	Starts counting from the last synchronized time, using the lidar's internal 1 Hz signal. Will gradually drift from the actual GPS time.

PPS status	μs time	Description
Unlocked	Not synchronized	The lidar's internal 1 Hz signal is not aligned with the GPS second.
Locked	Synchronized	The rising edge of the lidar's internal 1 Hz signal is aligned with the rising edge of the PPS signal (i.e. the start of each GPS second).
Lost	Drifting	Counts using the internal 1 Hz signal. Will gradually drift from the actual GPS second.

2) PTP as the Clock Source

- 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 µs)	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. The rising edge of the lidar's internal 1 Hz signal is aligned with the start of each PTP second.
Frozen	Drifting	Starts counting from the last synchronized time, using the lidar's internal 1 Hz signal. Will gradually drift from the actual GPS 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**

Definition

- Every time the lidar passes a fixed time Δt or azimuth interval Δα (see Section 4.2 Web Control – Trigger Method), it sends a command that triggers a round of firing.
- A round of firing can have either one or more returns (specified in Section 4.2 Web Control – Return Mode). The measurements of each return are stored in one block (see Section 3.1.2 UDP Data – Body).
- The absolute time of a Point Cloud Data Packet is the time when the lidar sends the command that triggers a round of firing that will be stored in the last block.
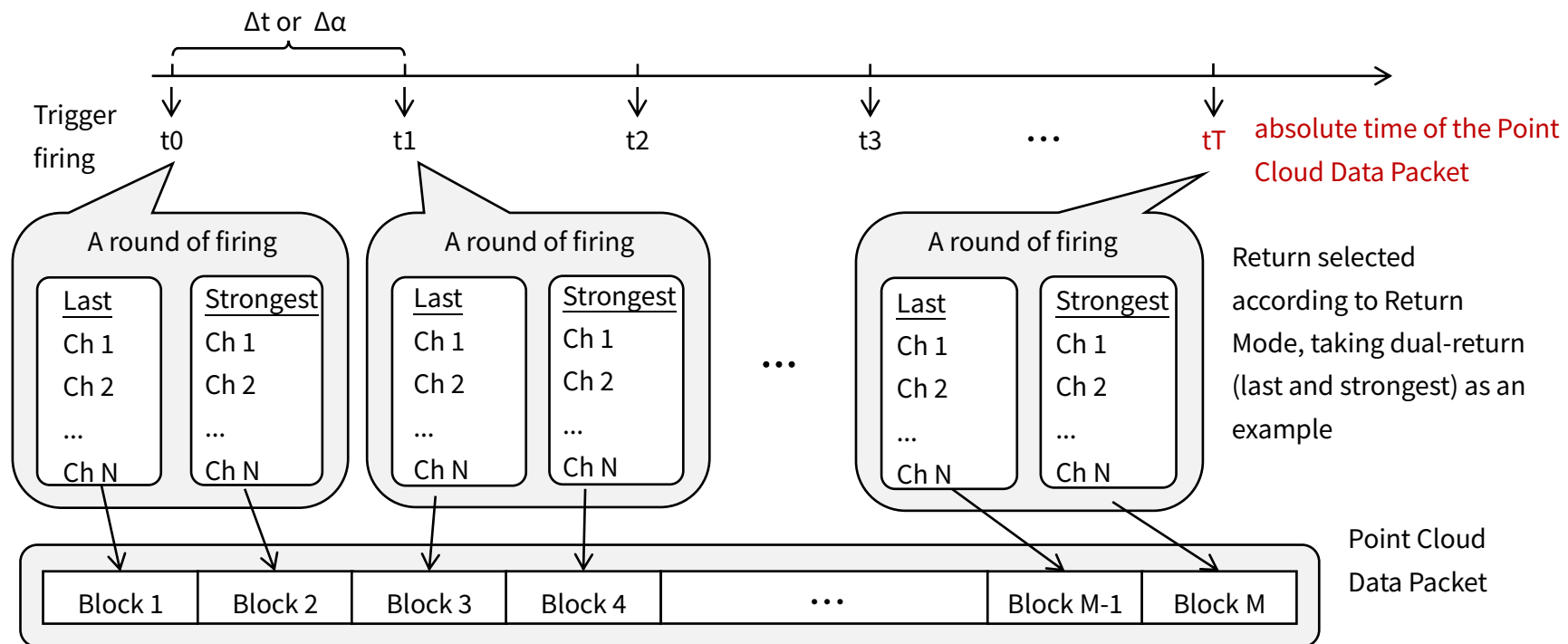
This absolute time is output to the **Date & Time** field and the **Timestamp** field in Point Cloud Data Packets.

■ **End Time of Each Block**

Assuming the absolute time of a Point Cloud Data Packet is t0, the end time of each block (i.e., time when the last firing ends) can be calculated.

	Block	End Time (μs)
Single Return Mode	Block 10	t0 - 28.58
	Block N	t0 - 28.58 - 55.56 * (10 - N)
	Block 3	t0 - 28.58 - 55.56 * 7
	Block 2	t0 - 28.58 - 55.56 * 8
	Block 1	t0 - 28.58 - 55.56 * 9

	Block	End Time (μs)
Dual Return Mode	Block 10 & Block 9	t0 - 28.58
	Block 8 & Block 7	t0 - 28.58 - 55.56 * 1
	Block 6 & Block 5	t0 - 28.58 - 55.56 * 2
	Block 4 & Block 3	t0 - 28.58 - 55.56 * 3
	Block 2 & Block 1	t0 - 28.58 - 55.56 * 4

■ Firing Time Offset of Each Channel

Assume that the end time of Block m is T(m), m ∈ {1, 2, ..., 10}, then the laser firing time of Channel n in Block m is t(m, n) = T(m) + Δt(n), n ∈ {1, 2, …, 40}. The lookup table of the firing time offsets Δt(n) is shown below.

| Firing Sequence	Channel #	Δt(n) (μs)	Firing Sequence	Channel #	Δt(n) (μs)
1	8	-54.67	17	14	-27.16
2	20	-52.7	18	26	-25.19
3	15	-50.73	19	21	-23.89
4	27	-48.76	20	31	-21.92
5	7	-47.46	21	13	-20.62
6	19	-45.49	21	9	-20.62
6	5	-45.49	22	25	-18.65
7	33	-43.52	23	35	-17.35
8	37	-42.22	24	39	-16.04
8	1	-42.22	24	3	-16.04
9	11	-40.91	25	17	-14.74
10	23	-38.95	26	29	-12.77
11	18	-36.98	27	24	-11.47
12	30	-35.01	28	32	-9.5
13	10	-33.71	29	16	-8.19
14	22	-31.74	29	12	-8.19
14	6	-31.74	30	28	-6.23
15	34	-29.77	31	36	-4.92
16	38	-28.47	32	40	-3.62
16	2	-28.47	32	4	-3.62

Appendix III   Phoenix Contact

Phoenix Contact can be used as the lidar's communication connector, in place of the default Lemo Contact in Section 2.2 (Interfaces).

Phoenix part number:

SACC-M12MS-8CON-PG 9-SH - 1511857 (male, on the lidar)   SACC-M12FS-8CON-PG 9-SH - 1511860 (female, on the connecting box)


From the eye to
the interface
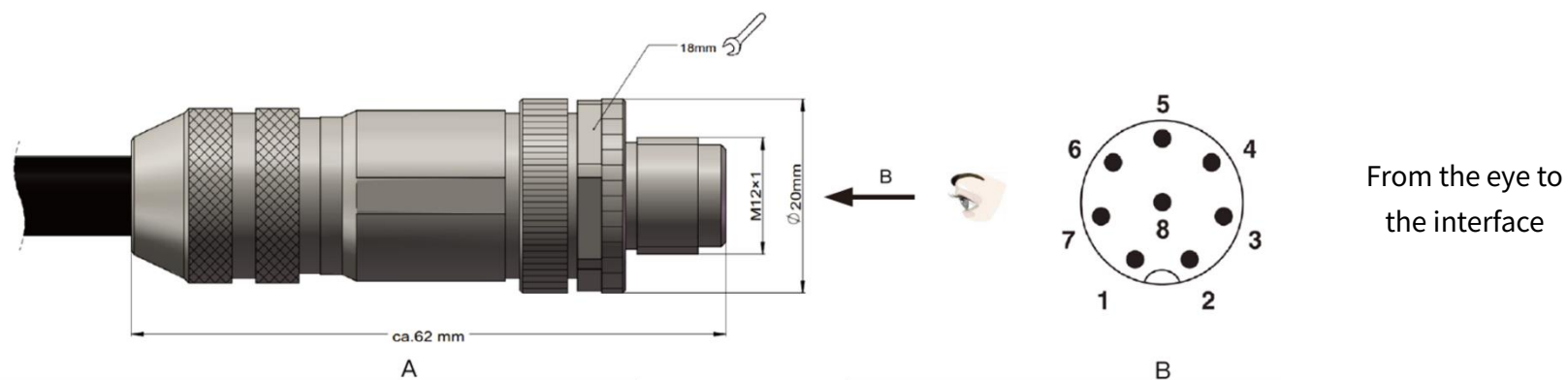
Pin #	Signal	Color	Voltage
1	Ethernet RX-	Blue	-1 V to 1 V
2	Ethernet RX+	Light Blue (Blue/White)	-1 V to 1 V
3	Ethernet TX-	Orange	-1 V to 1 V
4	Ethernet TX+	Light Orange (Orange/White)	-1 V to 1 V
5	GPS Serial Data	White	-13 V to +13 V
6	GPS PPS	Yellow	3.3 V/5 V
7	+12 V	Red	12 V
8	Ground (Return)	Black	-

Appendix IV   Nonlinear Reflectivity Mapping

By default, the 1-byte reflectivity data in Point Cloud Data Packets linearly represents target reflectivity from 0 to 255%.

Alternatively, users may choose the Nonlinear Mapping mode, see Chapter 4 (Web Control - Settings).

The nonlinear relationship is detailed below.
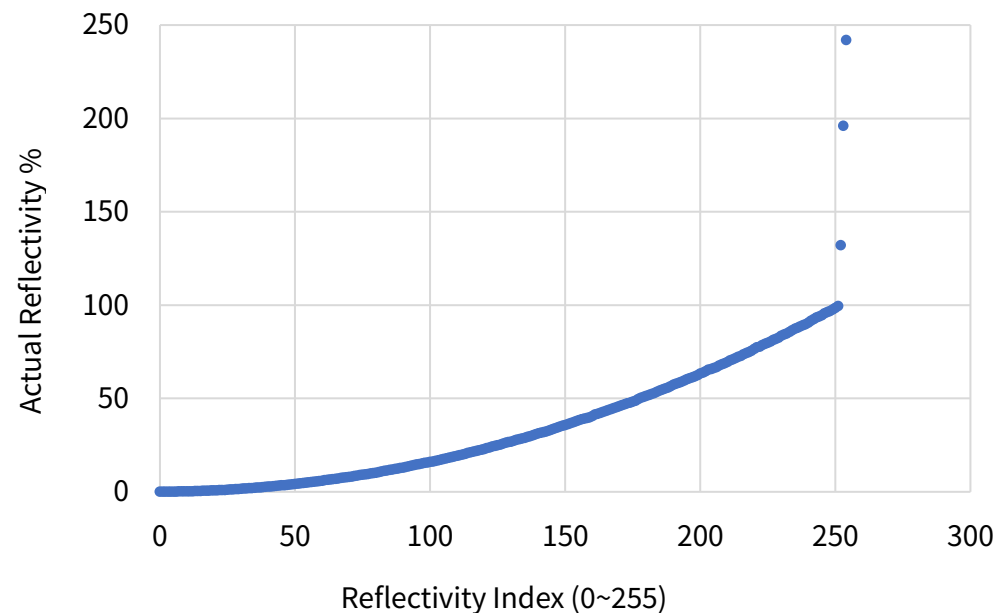
Nonlinear Reflectivity Mapping (Continued on the Next Page)

Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)
0	0	20	0.67	40	2.69	60	5.9
1	0.01	21	0.75	41	2.81	61	6.1
2	0.02	22	0.81	42	2.94	62	6.3
3	0.03	23	0.87	43	3.07	63	6.5
4	0.04	24	0.95	44	3.21	64	6.7
5	0.05	25	1.05	45	3.36	65	6.9
6	0.08	26	1.15	46	3.5	66	7.1
7	0.11	27	1.25	47	3.64	67	7.3
8	0.13	28	1.35	48	3.79	68	7.5
9	0.15	29	1.45	49	3.93	69	7.7
10	0.19	30	1.55	50	4.08	70	7.9
11	0.23	31	1.65	51	4.25	71	8.12
12	0.26	32	1.75	52	4.42	72	8.37
13	0.29	33	1.85	53	4.58	73	8.62
14	0.34	34	1.95	54	4.75	74	8.87
15	0.39	35	2.06	55	4.92	75	9.1
16	0.44	36	2.19	56	5.1	76	9.3
17	0.5	37	2.31	57	5.3	77	9.5
18	0.56	38	2.44	58	5.5	78	9.7
19	0.61	39	2.56	59	5.7	79	9.9

Nonlinear Reflectivity Mapping (Continued on the Next Page)

Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)
80	10.17	100	15.87	120	22.83	140	31.17
81	10.5	101	16.17	121	23.25	141	31.5
82	10.83	102	16.5	122	23.75	142	31.83
83	11.12	103	16.83	123	24.17	143	32.25
84	11.37	104	17.17	124	24.5	144	32.75
85	11.62	105	17.5	125	24.83	145	33.25
86	11.87	106	17.83	126	25.25	146	33.75
87	12.12	107	18.17	127	25.75	147	34.25
88	12.37	108	18.5	128	26.17	148	34.75
89	12.62	109	18.83	129	26.5	149	35.25
90	12.87	110	19.17	130	26.83	150	35.75
91	13.17	111	19.5	131	27.25	151	36.25
92	13.5	112	19.83	132	27.75	152	36.75
93	13.83	113	20.25	133	28.17	153	37.25
94	14.17	114	20.75	134	28.5	154	37.75
95	14.5	115	21.17	135	28.83	155	38.25
96	14.83	116	21.5	136	29.25	156	38.75
97	15.12	117	21.83	137	29.75	157	39.17
98	15.37	118	22.17	138	30.25	158	39.5
99	15.62	119	22.5	139	30.75	159	39.83

Nonlinear Reflectivity Mapping (Continued on the Next Page)

Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)	Reflectivity Index (0~255)	Reflectivity (%)
160	40.5	180	51.25	200	63.25	220	76.5
161	41.25	181	51.75	201	63.75	221	77.25
162	41.75	182	52.25	202	64.5	222	77.75
163	42.25	183	52.75	203	65.25	223	78.5
164	42.75	184	53.5	204	65.75	224	79.25
165	43.25	185	54.25	205	66.25	225	79.75
166	43.75	186	54.75	206	66.75	226	80.5
167	44.25	187	55.25	207	67.5	227	81.25
168	44.75	188	55.75	208	68.25	228	81.75
169	45.25	189	56.5	209	68.75	229	82.5
170	45.75	190	57.25	210	69.5	230	83.5
171	46.25	191	57.75	211	70.25	231	84.25
172	46.75	192	58.25	212	70.75	232	84.75
173	47.25	193	58.75	213	71.5	233	85.5
174	47.75	194	59.5	214	72.25	234	86.5
175	48.25	195	60.25	215	72.75	235	87.25
176	48.75	196	60.75	216	73.5	236	87.75
177	49.5	197	61.25	217	74.25	237	88.5
178	50.25	198	61.75	218	74.75	238	89.25
179	50.75	199	62.5	219	75.5	239	89.75

Reflectivity Index (0~255)	Reflectivity (%)
240	90.5
241	91.5
242	92.5
243	93.25
244	93.75
245	94.5
246	95.5
247	96.25
248	96.75
249	97.5
250	98.5
251	99.5
252	132
253	196
254	242

Appendix V   Legal Notice

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