HESAI

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PandarXT

32-Channel Medium-Range 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/zh/support

https://github.com/HesaiTechnology (Please leave your questions under the corresponding GitHub projects.)

■ Legends

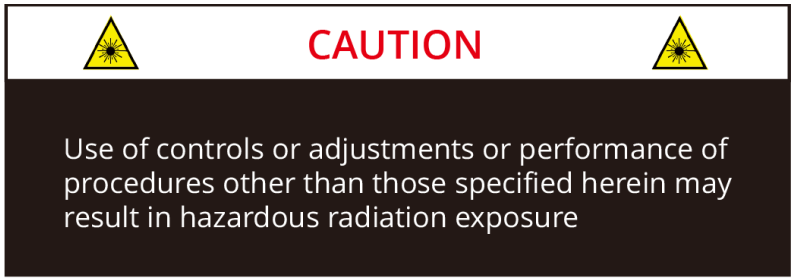
⚠ Warnings: instructions that must be followed to ensure safe and proper use of the product.

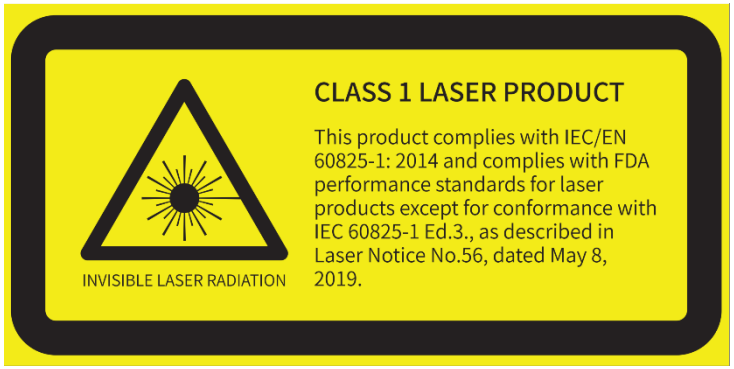
Notes: additional information that may be helpful.

Safety Notice

■ Special Warnings

Laser Safety





Hot Surface

During or after a period of operation, do NOT touch the product's enclosure with your skin.

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 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 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 format of PandarXT.

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

Laser emitters and receivers are attached to a motor that rotates horizontally.

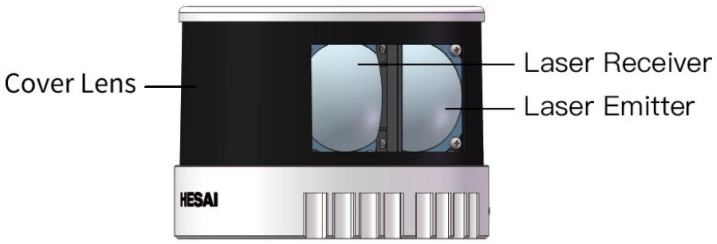


Figure 1.2 Partial Cross-Sectional Diagram

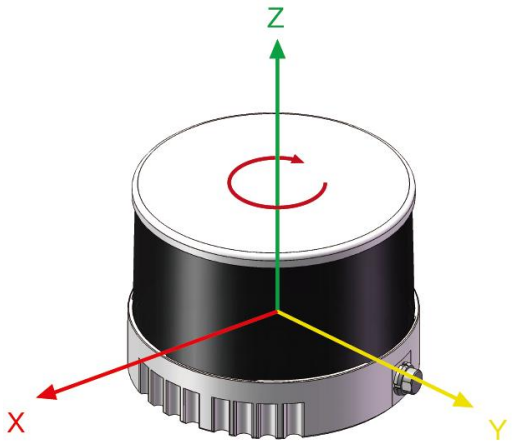


Figure 1.3 Coordinate System (Isometric View)

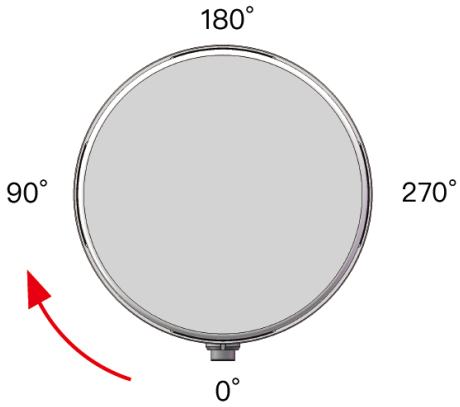


Figure 1.4 Rotation Direction (Top View)

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 on the next page. All measurements are relative to the origin.

When all channels pass the zero-degree position in Figure 1.4, the azimuth data in the corresponding UDP data block will be 0°.

1.3 Channel Distribution

The vertical resolution is 1° across the FOV, as shown in Figure 1.5.

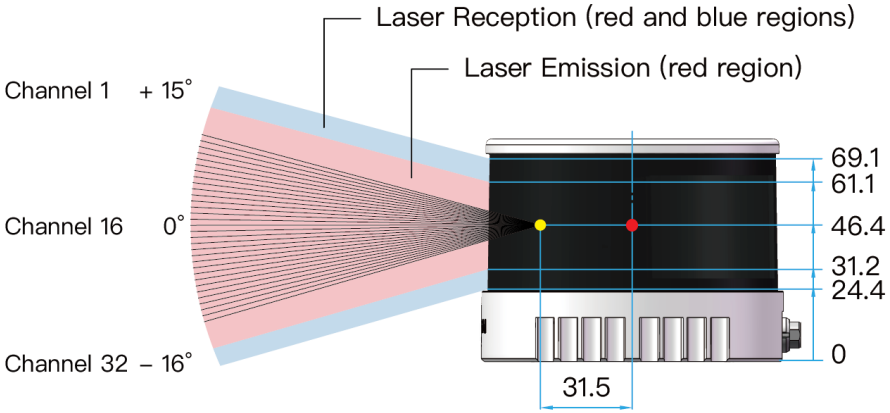


Figure 1.5 Channel Vertical Distribution

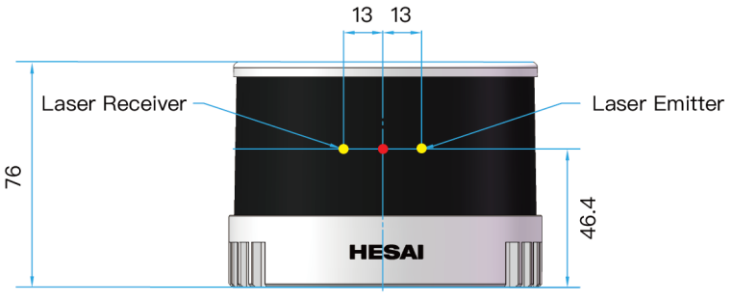


Figure 1.6 Laser Emitter/Receiver Position (Unit: mm)

Each channel has an intrinsic vertical angle offset.

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	32	
Instrument Range	0.05 to 120 m	
Range Capability ①	80 m @10% reflectivity (Channels 9 to 24)	
	50 m @10% (Channels 1 to 8, 25 to 32)	
Range Accuracy ②	±1 cm	
Range Precision ②	0.5 cm	
FOV (Horizontal)	360°	
Resolution (Horizontal)	0.09°	(5 Hz)
	0.18°	(10 Hz)
	0.36°	(20 Hz)
FOV (Vertical)	31° (-16° to +15°)	
Resolution (Vertical)	1°	
Frame Rate	5 Hz, 10 Hz, 20 Hz	
Returns	Single Return (Last, Strongest, First)	
	Dual Return	

MECHANICAL/ELECTRICAL/OPERATIONAL		
Wavelength	905 nm	
Laser Class	Class 1 Eye Safe	
Ingress Protection	IP6K7	
Dimensions	Height:	76.0 mm
	Top/Bottom:	Φ100.0 / 103.0 mm
Rated Voltage Range	DC 9 to 36 V	
Power Consumption ③	10 W	
Operating Temperature	-20°C to 65°C	
Storage Temperature	-40°C to 85°C	
Weight	0.8 kg	

DATA I/O		
Data Transmission	UDP/IP Ethernet (100 Mbps)	
Measurements	Distance, Azimuth Angle, Intensity	
Data Points Generated	Single Return:	640,000 points/sec
	Dual Return:	1,280,000 points/sec
Point Cloud Data Rate	Single Return:	22.44 Mbps
	Dual Return:	44.88 Mbps
Clock Source	GPS / PTP	
PTP Clock Accuracy ④	≤1 µs	
PTP Clock Drift ④⑤	≤1 µs/s	

Specifications are subject to change. Please refer to the latest version. (Continued on the next page)

(Continued)

① Range capability: typical value

- Test conditions: 100 klux ambient intensity, PoD (probability of detection) > 90%

② Range accuracy and precision: typical value

- May vary with range, temperature, and target reflectivity.
- The typical values are the average among channels 9 to 24, measured outdoors within 0.5 ~ 70 m, under 30°C ambient temperature, and with a target reflectivity of 50%.

③ Power Consumption: typical value

- Test conditions: room temperature, 12 V (LiDAR input voltage), 600 rpm (spin rate)
- Not including accessories such as the connection box.

④ PTP Clock Accuracy and Clock Drift: typical value

- Test conditions: room temperature

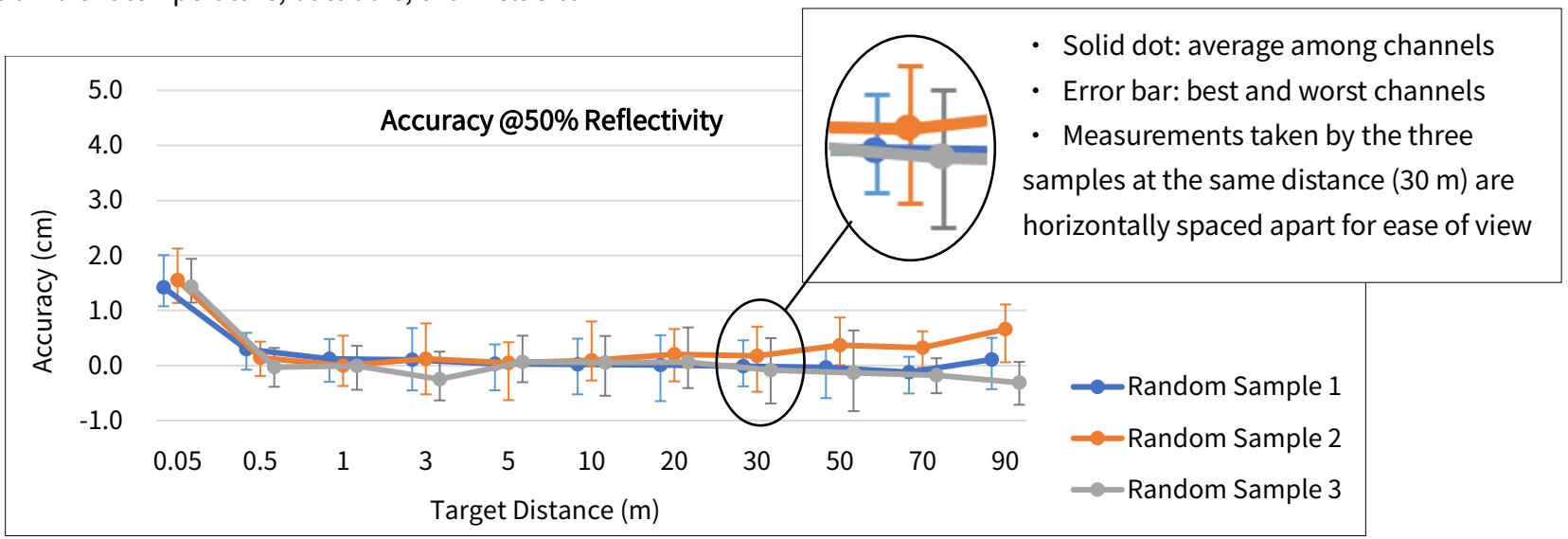
⑤ PTP Clock Drift

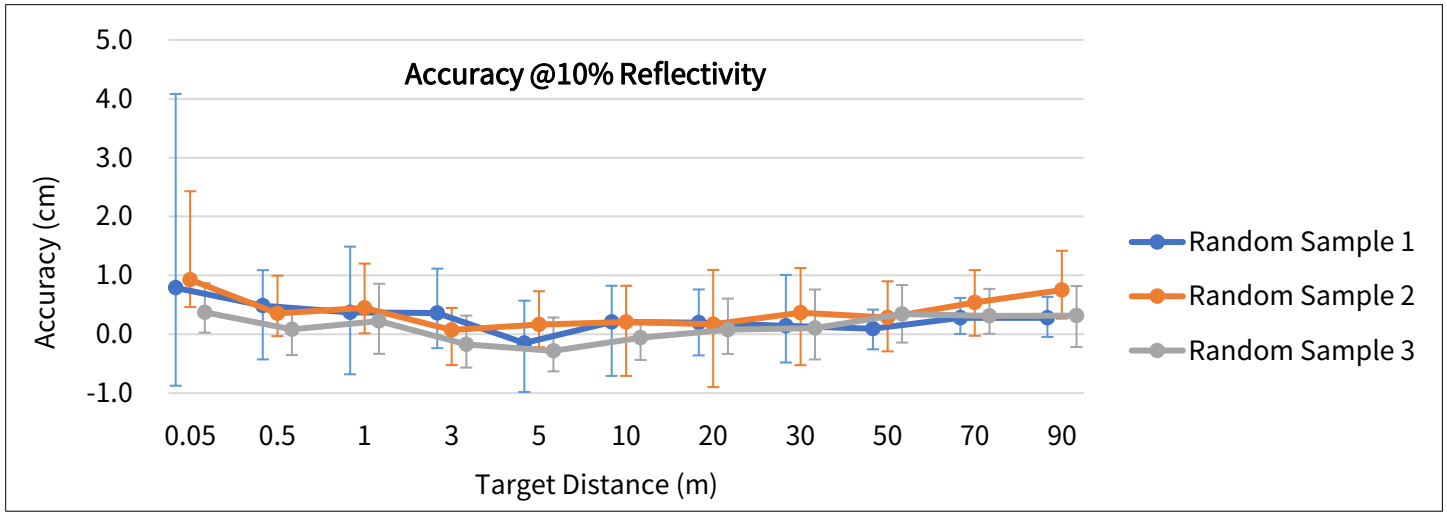
- Defined as the drift at a constant temperature after the LiDAR (slave clock) loses connection to the PTP master.

■ Range Accuracy

Definition: the average of the differences between multiple measurements and the target's true distance, measured by a single channel

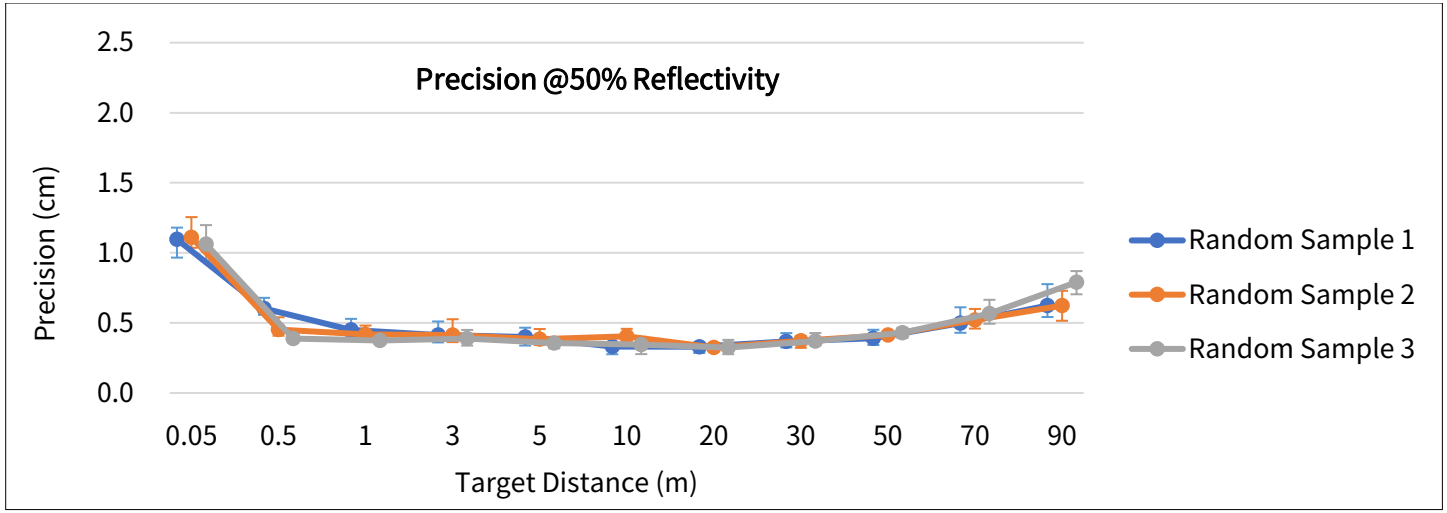
Conditions: 30°C ambient temperature, outdoors; channels 9 to 24

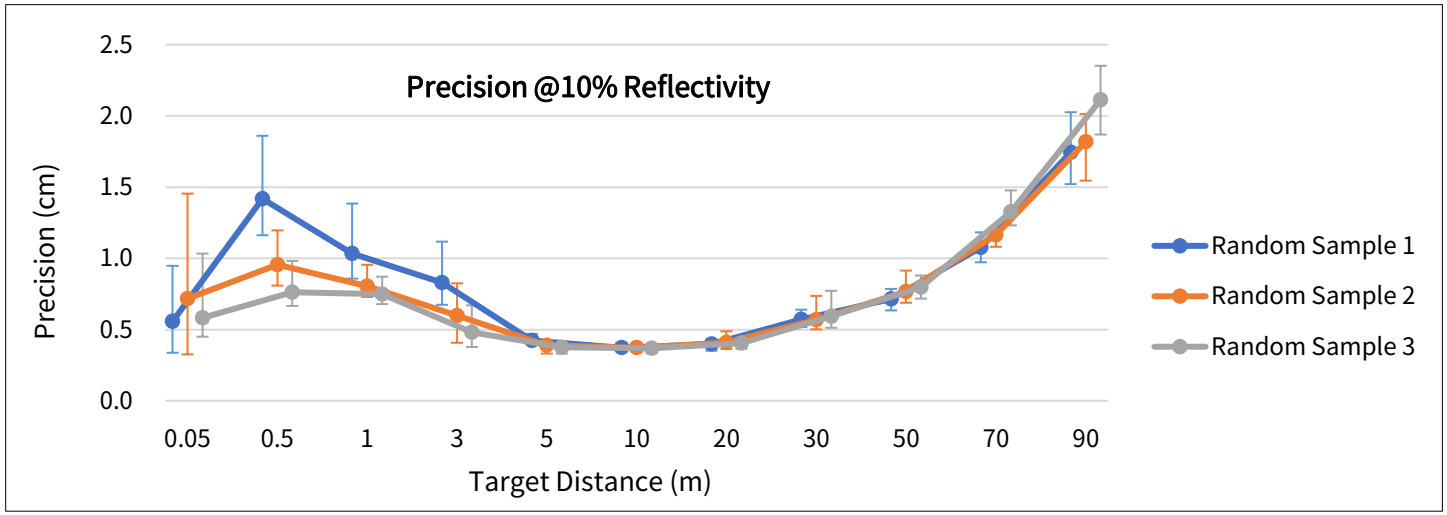




■ Range Precision

Definition: the standard deviation among multiple measurements, measured by a single channel
Conditions: 30°C ambient temperature, outdoors; channels 9 to 24





2 Setup

2.1 Mechanical Installation

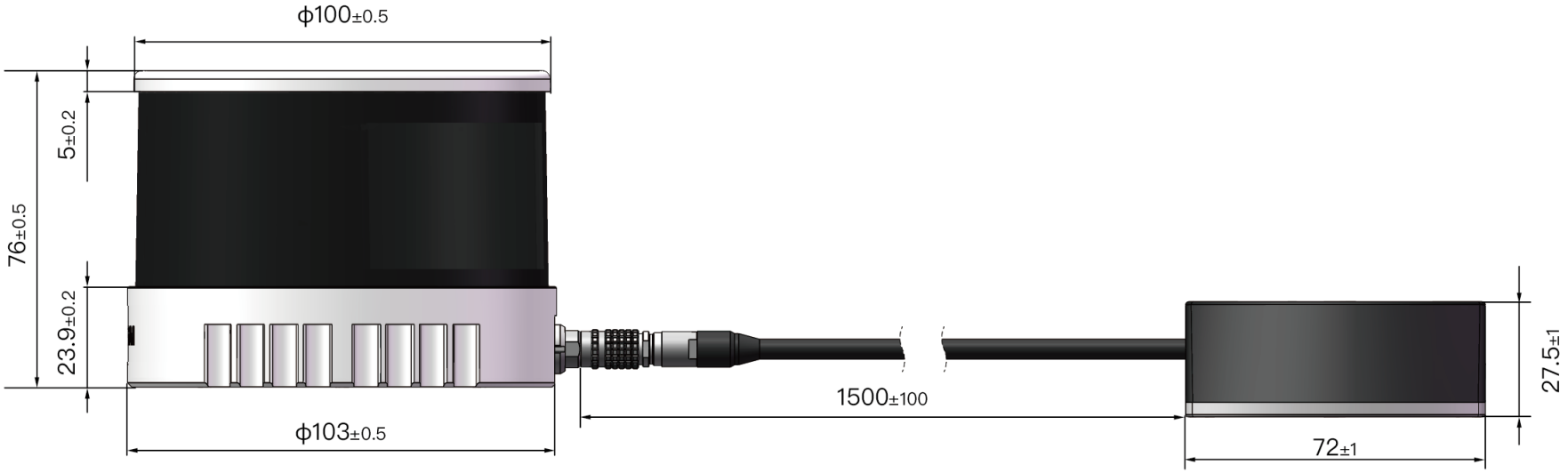


Figure 2.1 Front View (Unit: mm)

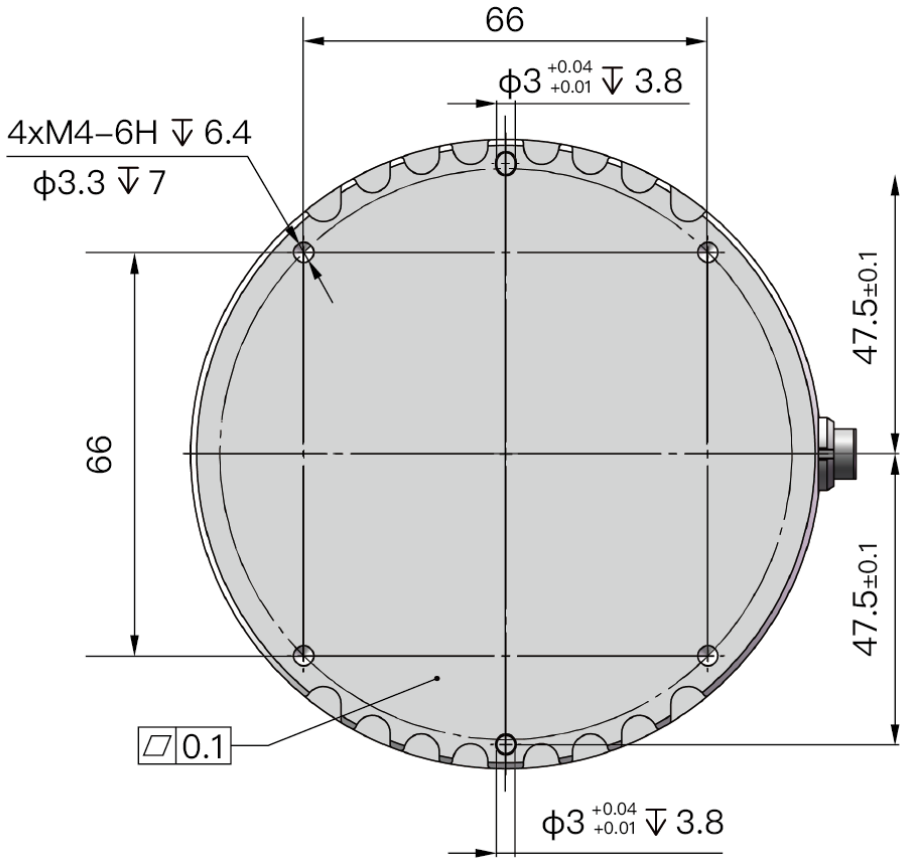


Figure 2.2 Bottom View (Unit: mm)

■ Recommended Installation

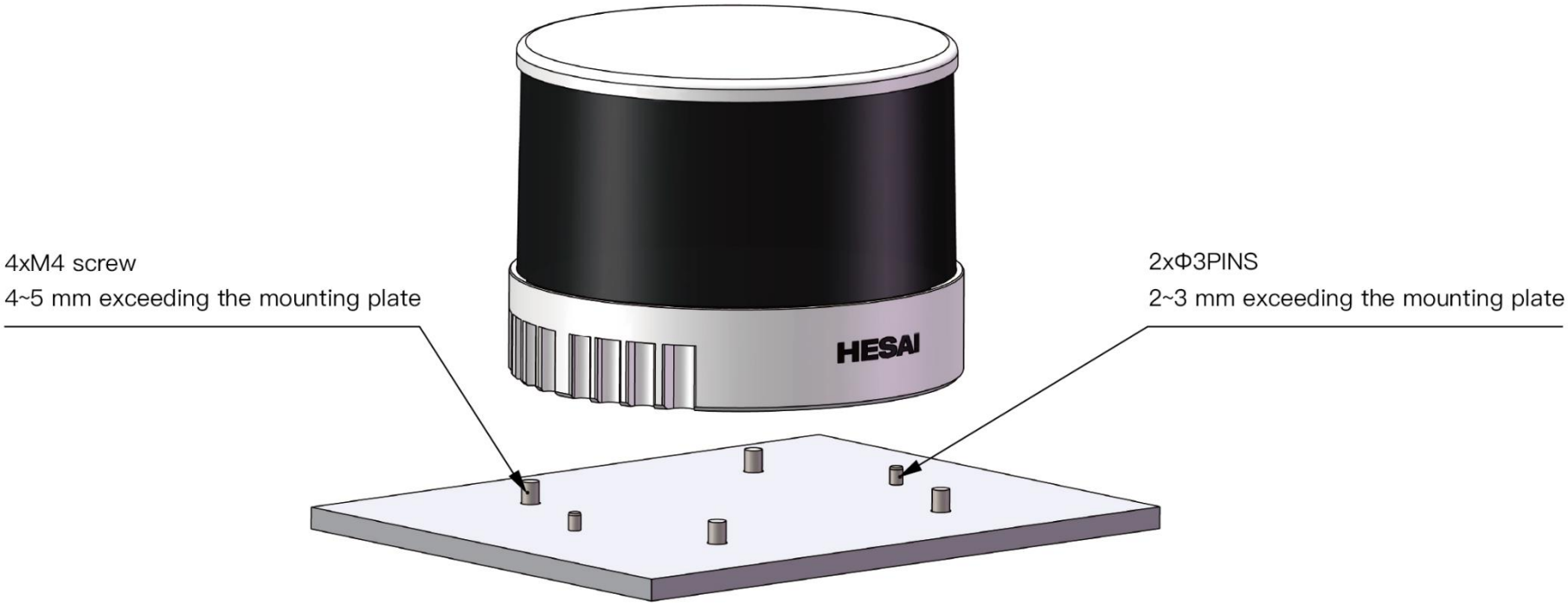


Figure 2.3 Recommended Installation

2.2 Interfaces

Lemo part number: EEG.0T.309.CLN (female socket, on the LiDAR)

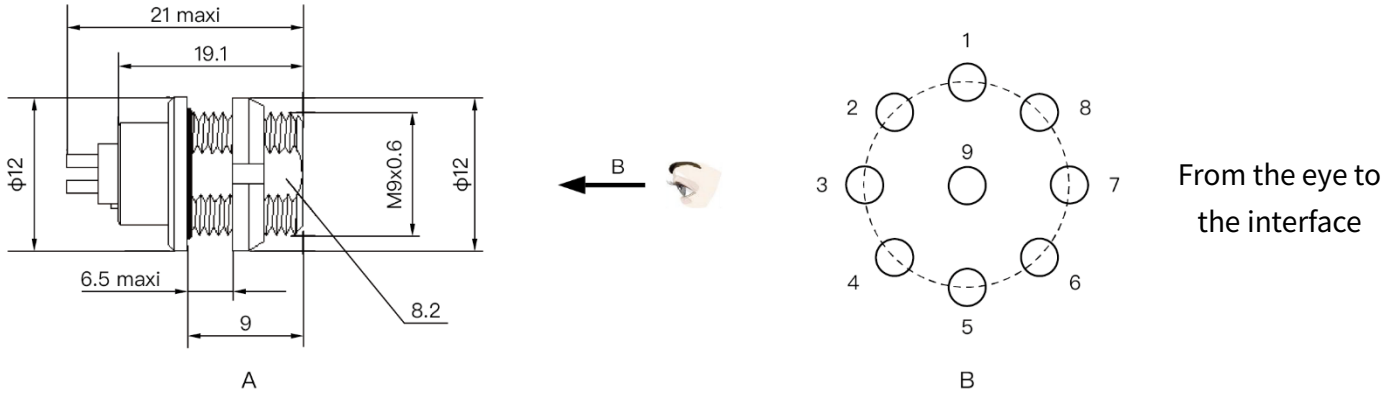


Figure 2.4 Lemo Connector (Female Socket)

Pin #	Signal	Wire Color	Voltage	Wire Gauge
1	GPS PPS	BLACK	3.3 to 5 V	28 AWG
2	GPS DATA	PURPLE	-13 to +13 V	28 AWG
3	GND	BROWN	0 V	26 AWG
4	VIN	WHITE	9 to 36 V	26 AWG
5	Ethernet TX+	YELLOW	-1 to 1 V	28 AWG

Pin #	Signal	Wire Color	Voltage	Wire Gauge
6	Ethernet TX-	GREEN	-1 to 1 V	28 AWG
7	Ethernet RX+	PINK	-1 to 1 V	28 AWG
8	Ethernet RX-	GRAY	-1 to 1 V	28 AWG
9	GND	RED	0 V	28 AWG

(continued on the next page)

(continued)

Notes

- 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).
- The blue wire is not used. Pin 9 may be reserved in previous batches.

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

■ Connector Use

Connection	Disconnection
• Turn off the power source. • Make sure the red dot on the cable's plug faces upward, so that the alignment key matches the slot on the LiDAR side. • Push the plug straight into the LiDAR's socket.	• Turn off the power source. • Hold the plug's shell and pull the plug straight from the socket.

⚠ 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.

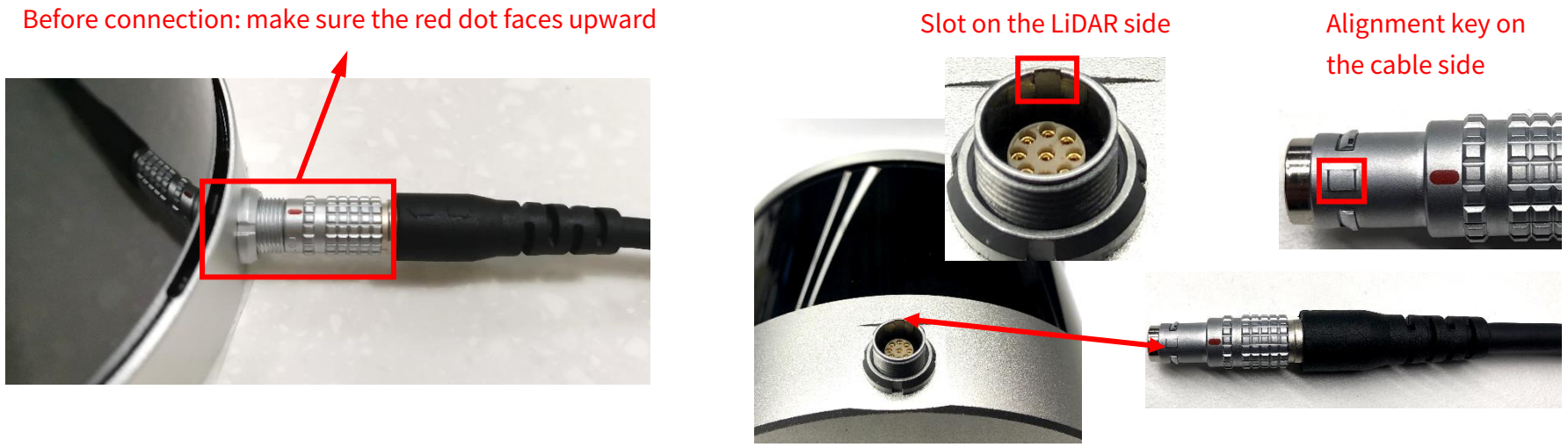


Figure 2.5 Lemo Connection

■ Cables

OD (outside diameter) = 5.0±0.2 mm
Minimum bend radius: 10 * OD

2.3 Connection Box (Optional)

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

Lemo part number: FGG.0T.309.CLAC50Z (male plug, on the connection box)

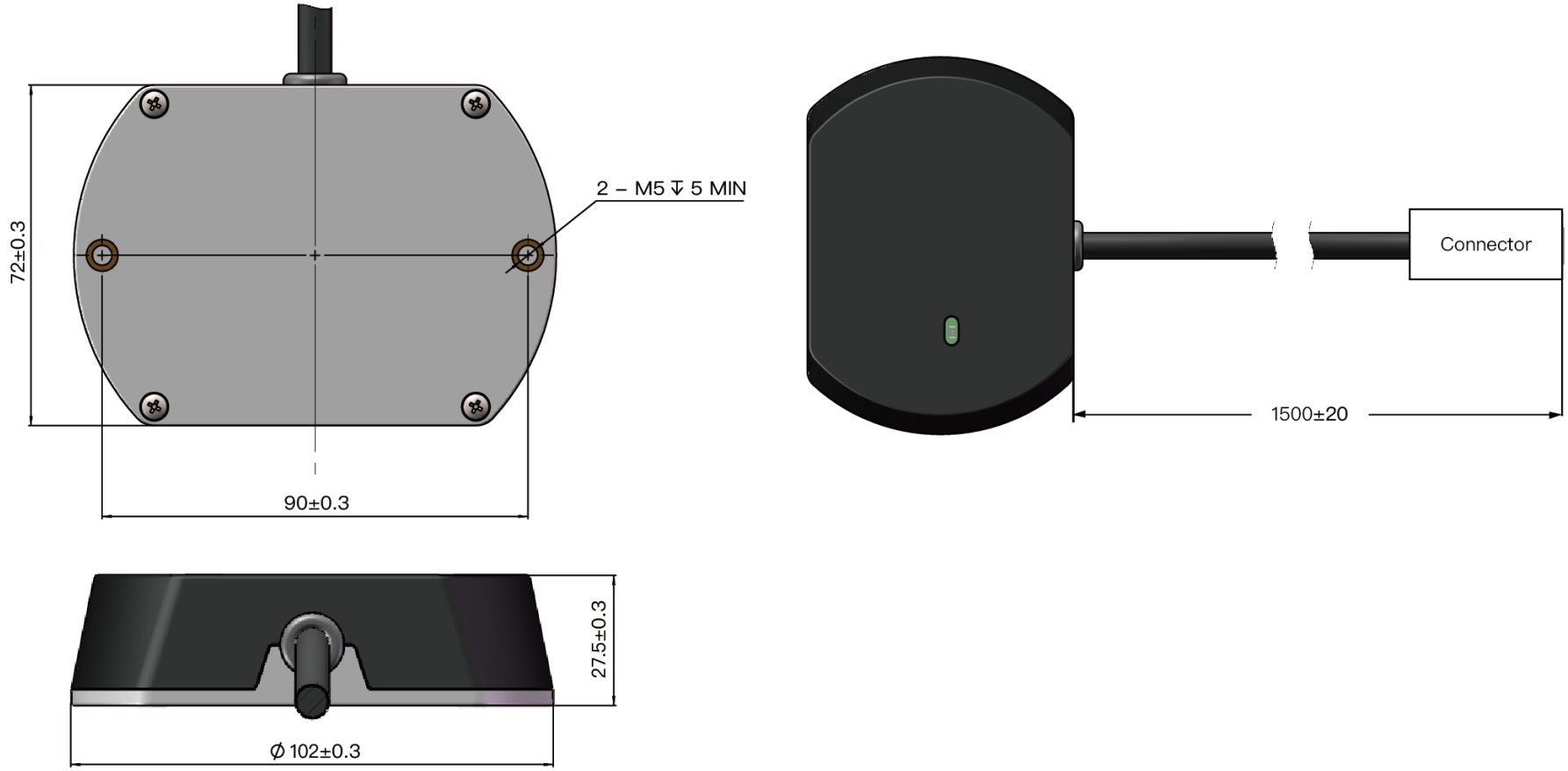


Figure 2.6 Connection Box (Unit: mm)

2.3.1 Connection Box Interfaces

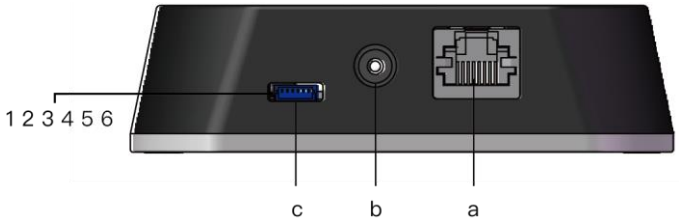


Figure 2.7 Connection Box (Front)

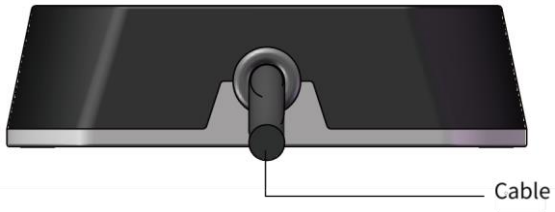


Figure 2.8 Connection Box (Back)

Port #	Port Name	Description
a	Standard Ethernet Port	RJ45, 100 Mbps Ethernet
b	Power Port	Connects to a DC power adapter External power supply: 9 V to 36 V, at least 30 W
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	3.3 V to 5 V Rising edge ⩽500 ns 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

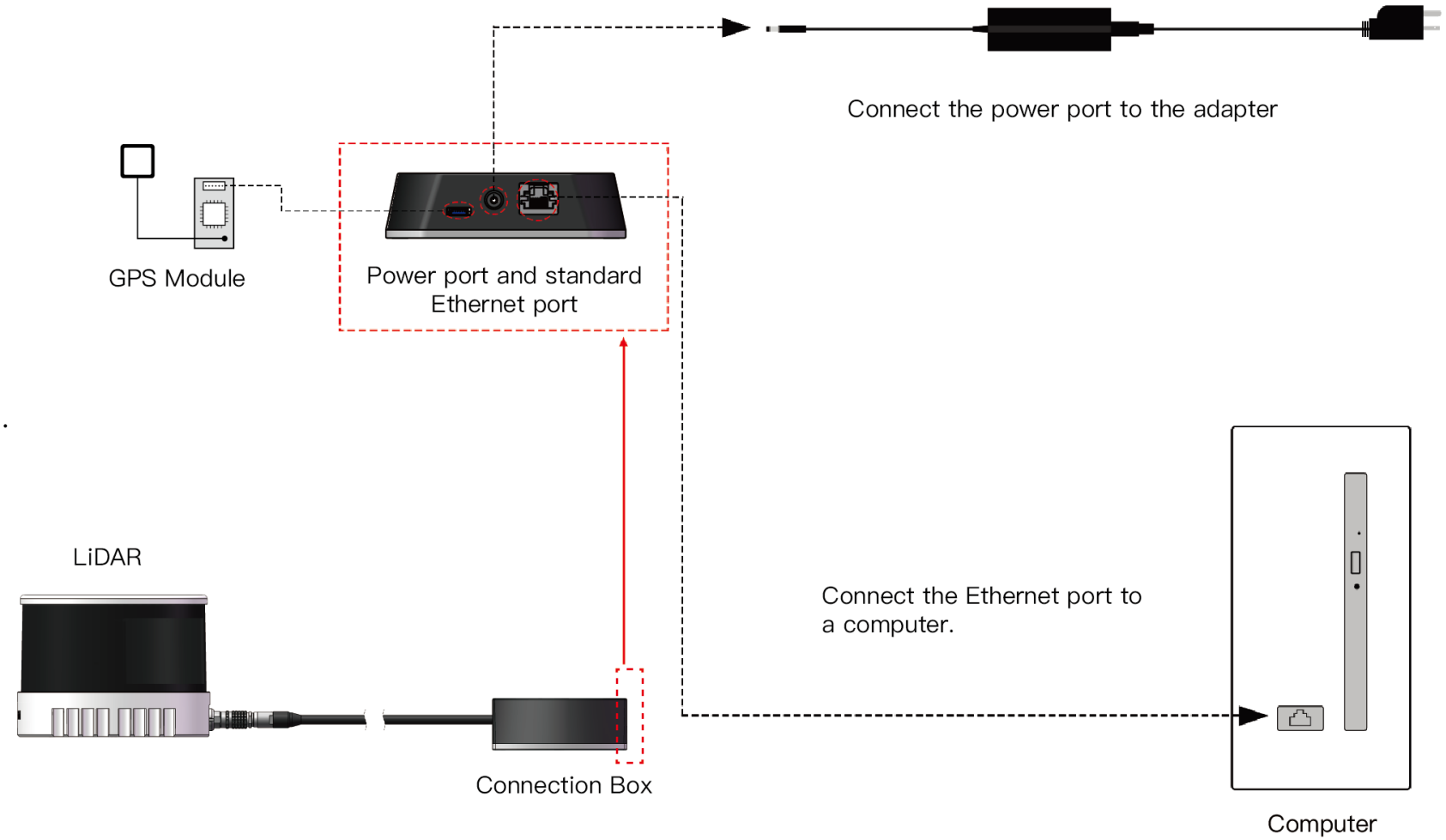


Figure 2.9 Connection Box - Connection

Refer to Appendix III when PTP protocol is used.

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.
Each data packet consists of an Ethernet header and UDP data.
Unless otherwise specified, all the multi-byte fields are unsigned values in little endian format.

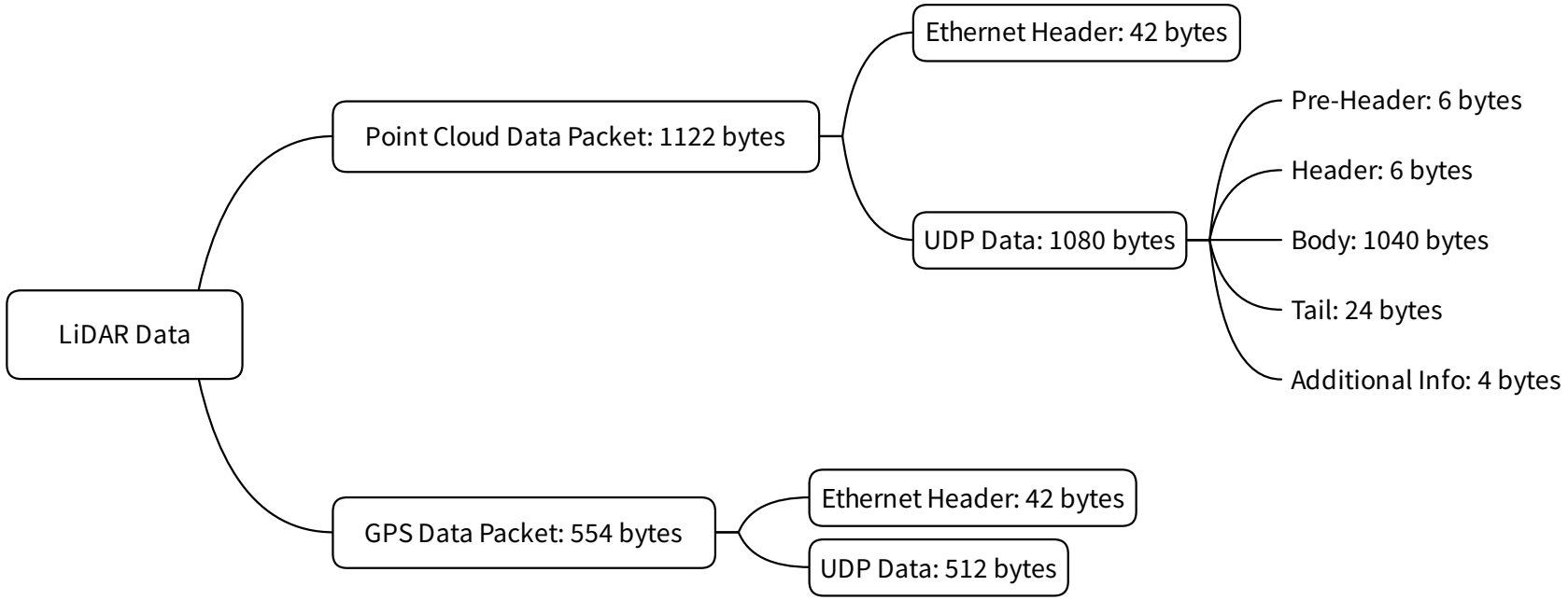


Figure 3.1 Data Structure

3.1 Point Cloud Data Packet

3.1.1 Ethernet Header

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 bytes	Destination: broadcast (0xFF: 0xFF: 0xFF: 0xFF: 0xFF: 0xFF) Source: (xx:xx:xx:xx:xx:xx)
Ethernet Data Packet Type	2 bytes	0x08, 0x00
Internet Protocol	20 bytes	Shown in Figure 3.2
UDP Port Number	4 bytes	UDP source port (0x2710, representing 10000) Destination port (0x0940, representing 2368)
UDP Length	2 bytes	0x0440, representing 1088 bytes (8 bytes more than the size of the Point Cloud UDP Data, shown in Figure 3.1)
UDP Checksum	2 bytes	Shown in the figure below

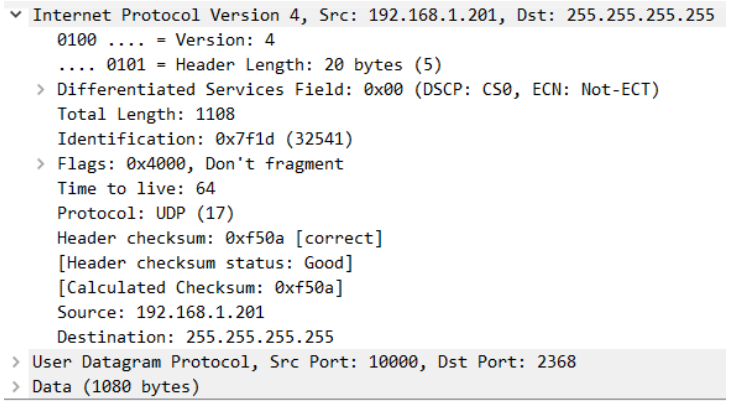


Figure 3.2 Point Cloud Ethernet Header - Internet Protocol

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	To distinguish between product models Currently 0x06
Protocol Version Minor	1	For each product model, to indicate the current protocol version Currently 0x01
Reserved	2	-

■ **Header: 6 bytes**

Header		
Field	Bytes	Description
Laser Num	1	0x20 (32 channels)
Block Num	1	0x08 (8 blocks per packet)
First Block Return	1	Reserved
Dis Unit	1	0x04 (4 mm)
Return Number	1	0x02 (each channel can generate two returns maximum)
UDP Seq	1	[7:1] is reserved Least significant bit [0] shows whether this packet includes a UDP sequence number field 1 - UDP sequence ON

■ **Body: 1040 bytes (8 blocks)**

Block 1	**Block 2**	**Block 3**	**...**	**Block 8**
Azimuth 1	Azimuth 2	Azimuth 3	...	Azimuth 8
Channel 1	Channel 1	Channel 1	...	Channel 1
Channel 2	Channel 2	Channel 2	...	Channel 2
...	...	...	...	...
Channel 32	Channel 32	Channel 32	...	Channel 32

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

Block size = size of Azimuth + 32 * size of Channel X

Each Block in the Body: 130 bytes			
Field	Bytes	Description	
Azimuth	2	Current reference angle of the rotor Unit: 0.01°	
Channel X	4	2-byte Distance	Distance Value = Distance * Dis Unit See the Dis Unit field in the Header.
		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)
		Reserved	-

■ **Tail: 24 bytes**

<table>
<tr><th>Field</th><th>Bytes</th><th>Description</th></tr>
<tr><td>Reserved</td><td>9</td><td>-</td></tr>
<tr><td>High Temperature Shutdown Flag</td><td>1</td><td>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</td></tr>
<tr><td>Return Mode</td><td>1</td><td>0x33 - First Return
0x37 - Strongest Return
0x38 - Last Return
0x39 - Dual Return (Last, Strongest)
0x3B - Dual Return (Last, First)
0x3C - Dual Return (First, Strongest)</td></tr>
<tr><td>Motor Speed</td><td>2</td><td>Unit: RPM</td></tr>
<tr><td>Date & Time</td><td>6</td><td>The absolute UTC time of this data packet, accurate to the second.

<table><tr><th>Each Byte</th><th>Range</th></tr><tr><td>Year (current year minus 1900)</td><td>⩾70</td></tr><tr><td>Month</td><td>1 to 12</td></tr><tr><td>Day</td><td>1 to 31</td></tr><tr><td>Hour</td><td>0 to 23</td></tr><tr><td>Minute</td><td>0 to 59</td></tr><tr><td>Second</td><td>0 to 59</td></tr></table></td></tr>
<tr><td>Timestamp</td><td>4</td><td>The "μs time" part of the absolute time of this data packet (defined in Appendix II)
Unit: μs
Range: 0 to 1000000 μs (1 s)</td></tr>
<tr><td>Factory Information</td><td>1</td><td>0x42</td></tr>
</table>

■ **Additional Info: 4 bytes**

Field	Bytes	Description
UDP Sequence	4	Sequence number of this UDP packet 0 to 0xFF FF FF FF

3.1.3 Point Cloud Data Analysis

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

■ **Analyze the vertical angle, horizontal angle, and distance of a data point**

Take Channel 5 in Block 2 as an example:

1) Vertical angle of Channel 5 is 11°, according to Appendix I (Channel Distribution)

The accurate vertical angle is recorded in this LiDAR's unit's angle correction file, see Section 1.3 (Channel Distribution).

- 0° represents the horizontal direction
- Define upward as positive
- The Channel # from the uppermost counts from 1

2) Horizontal angle = current reference angle of the rotor + horizontal angle offset + firing time angular offset

- Current reference angle of the rotor: Azimuth field of Block 2
- Horizontal angle offset: 0° for Channel 5, according to Appendix I (Channel Distribution)
- Firing time angular offset = Firing Time Offset of Channel 5 (see Appendix II) * Spin Rate of the Motor (see Section 4.1 Web Control - Home)
- Define clockwise in the top view as the horizontal angles' positive direction

3) Actual distance in real world millimeters = distance measurement * Distance Unit (4 mm)

Distance measurement is the Distance field of Channel 5 in Block 2

■ **Draw the data point in a spherical 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

GPS Data Packets are triggered every second.

Before NMEA messages are available from the external GPS module

Each rising edge of the LiDAR's internal 1 Hz signal triggers a GPS Data Packet.
The time and date in the GPS Data Packets are unreal, starting from 20 05 20 00 00 00 (year, month, day, hour, minute, second) and increasing with the internal 1 Hz signal.

Once the LiDAR receives the PPS (pulse-per-second) signal and NMEA messages

The internal 1 Hz signal will be locked to the PPS. Each rising edge still triggers a GPS Data Packet.
Meanwhile, the LiDAR will extract the actual date and time from NMEA messages ($GPRMC or $GPGGA), and stamp them into both Point Cloud Data Packets and GPS Data Packets.

- Point Cloud Data Packets: 6-byte Date & Time (year, month, day, hour, minute, second)
- GPS Data Packets: 6-byte Date (year, month, day) and 6-byte Time (second, minute, hour)

The GPS module sends first the PPS signal and then the NMEA message. At the rising edge of the PPS pulse, the corresponding NMEA message is not yet available. Therefore, the LiDAR extracts date and time from the previous NMEA message and automatically adds 1 full second.

When GPS signal is lost

The LiDAR will still trigger GPS Data Packets by the rising edge of the internal 1 Hz signal. However, the GPS time in the packets will be counted by the internal 1 Hz signal and will drift from the actual GPS time.

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	-

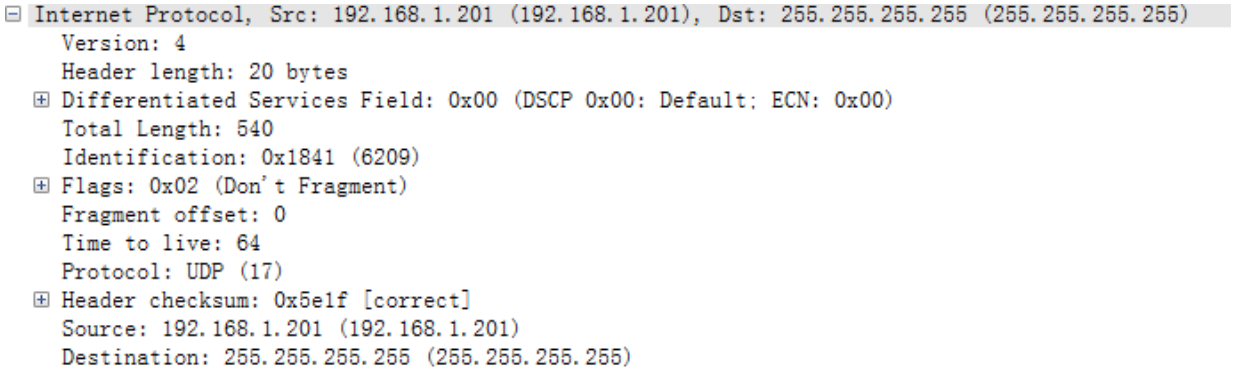


Figure 3.3 GPS Ethernet Header - Internet Protocol

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
		µs Time	4 bytes	In units of µs (lower byte first)
GPRMC/GPGGA Data	100	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 Section 4.2 (Web Control - Settings)		
Reserved	388	388 bytes of 0xDF		
GPS Positioning Status	1	ASCII code, obtained from $GPRMC or $GPGGA When $GPRMC is selected: A (hex = 41) for Valid Position V (hex = 56) for Invalid Position NUL (hex = 0) for GPS being unlocked When $GPGGA is selected: 0 = invalid 1 = GPS fix (SPS) 2 = DGPS fix 3 = PPS fix 6 = estimated (dead reckoning)		
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

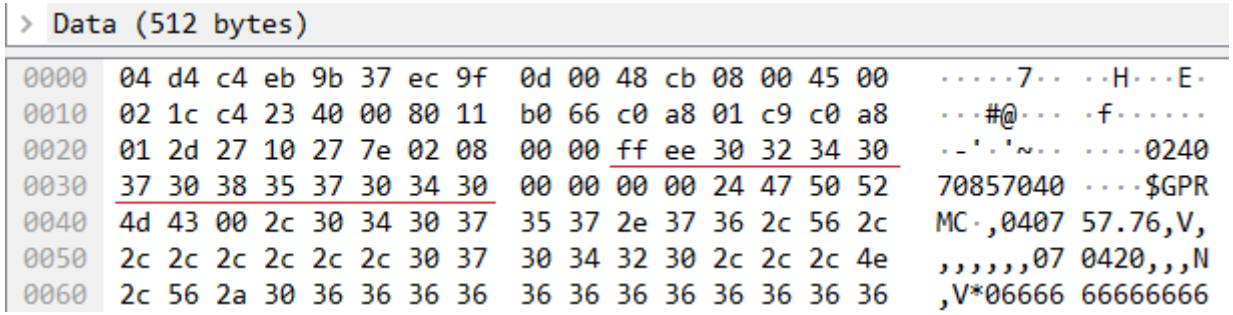


Figure 3.3 GPS Data Packet - UDP Data (Example)

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

This screenshot may not display the most current version numbers. See Section 4.5 (Upgrade).

Spin Rate of the motor (revs per minute) = frame rate (Hz) * 60

GPS (PPS) Status

Lock	LiDAR's internal clock is in sync with GPS
Unlock	Not in sync

NMEA (GPRMC/GPGGA) Status

Lock	After receiving a valid NMEA message
Unlock	No valid NMEA message for over 2 s, or having detected a checksum error in GPS packets

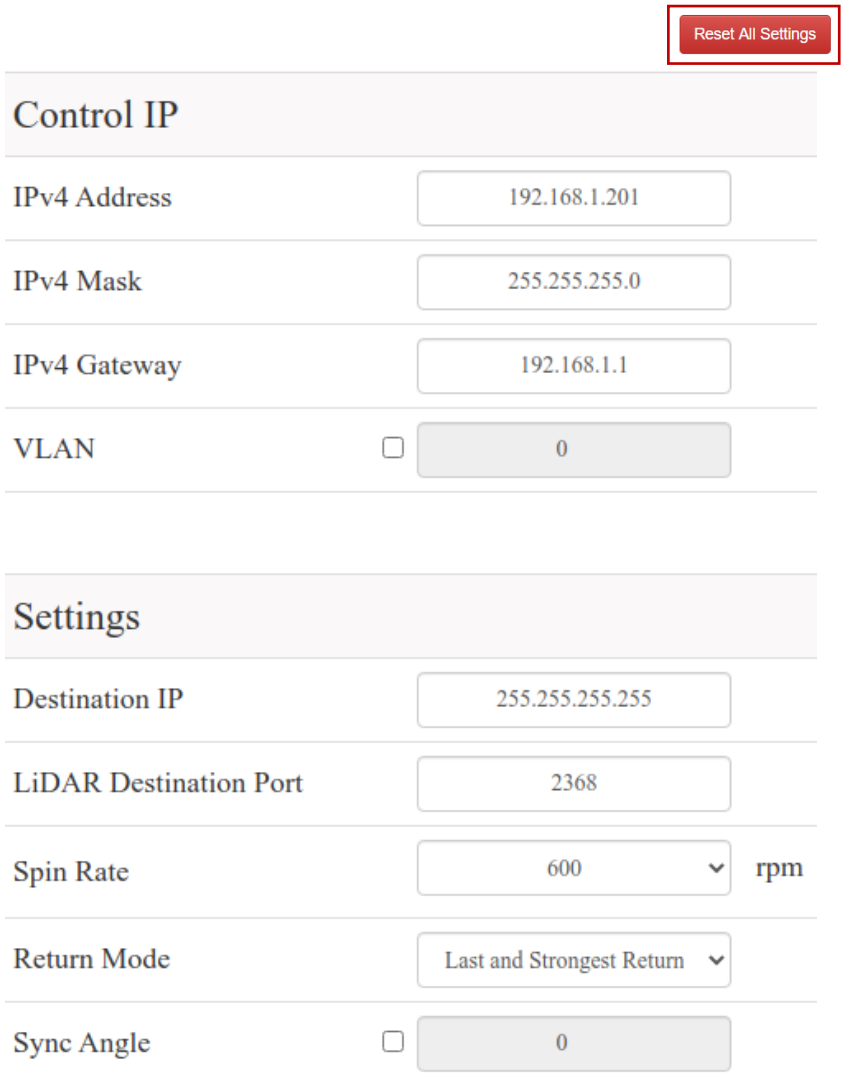
PTP Status

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. Also, drifting from the previous clock; when drifting out of specifications, will go back to the Free Run mode.

Device Log

Click to download a .JSON file containing the LiDAR's status, device info, all configurable parameters, and upgrade log.

4.2 Settings



(continued on the next page)

In the Settings page

- Standby Mode: effective immediately
- All other settings: effective after clicking the "Save" button at the bottom

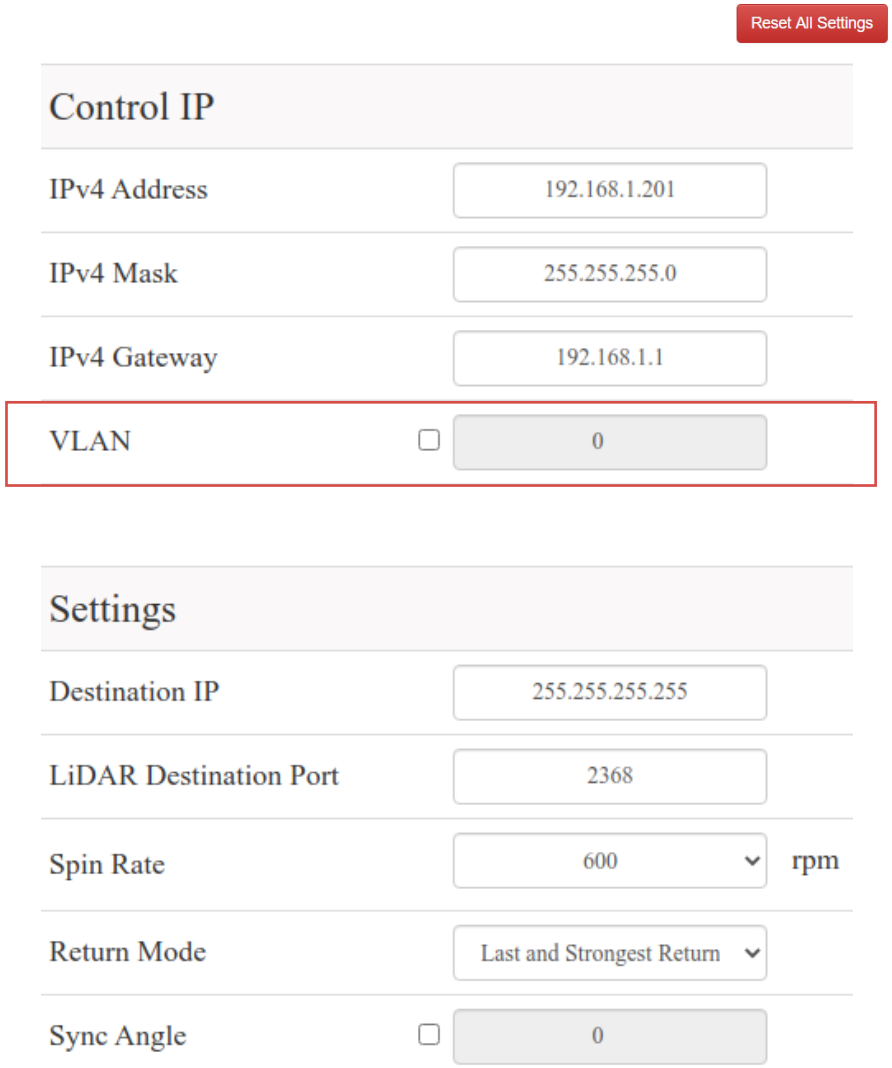
1. Reset All Settings

By clicking the "Reset All Settings" button on the top-right corner, all configurable parameters on web control will be reset to factory defaults.

The default values are shown in the screenshots in

- Section 4.2 (Settings)
- Section 4.3.1 (Azimuth FOV - for All Channels)

(continued)



2. Control IP

VLAN Tagging	(VLAN ID) 1 to 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. **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.

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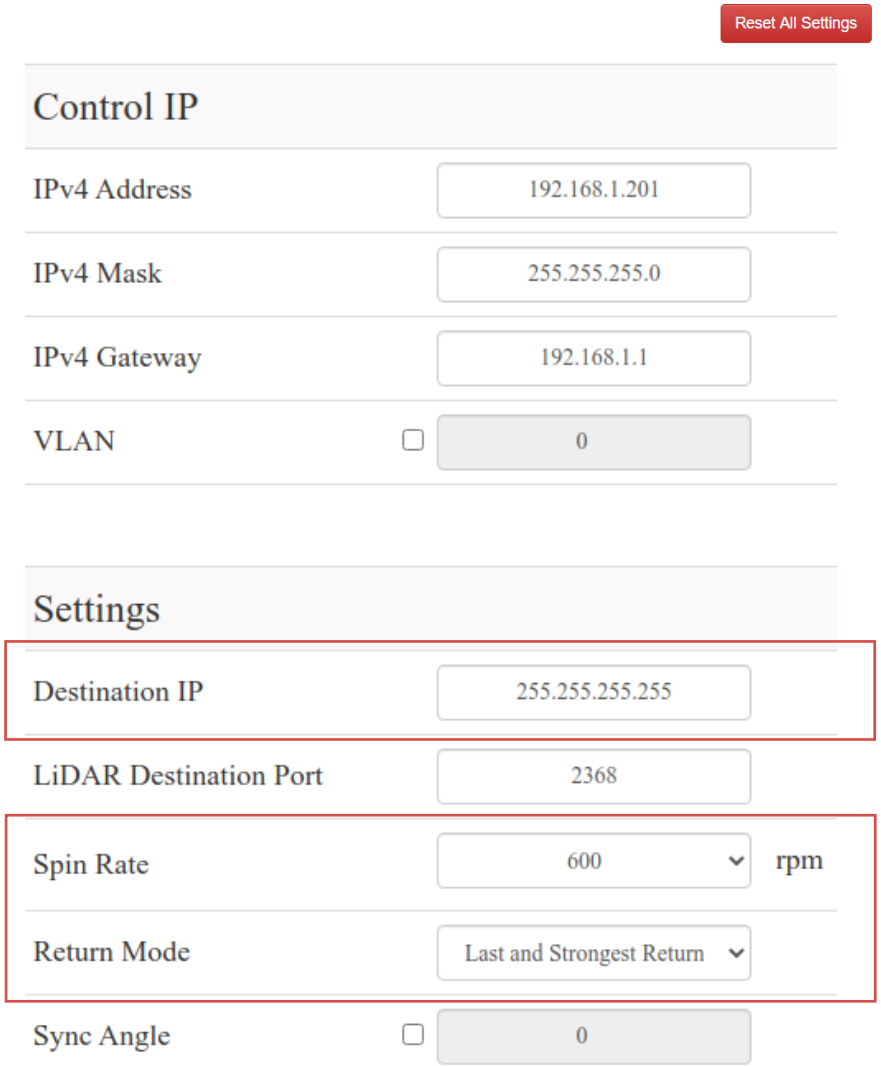
(continued)



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3. Destination IP

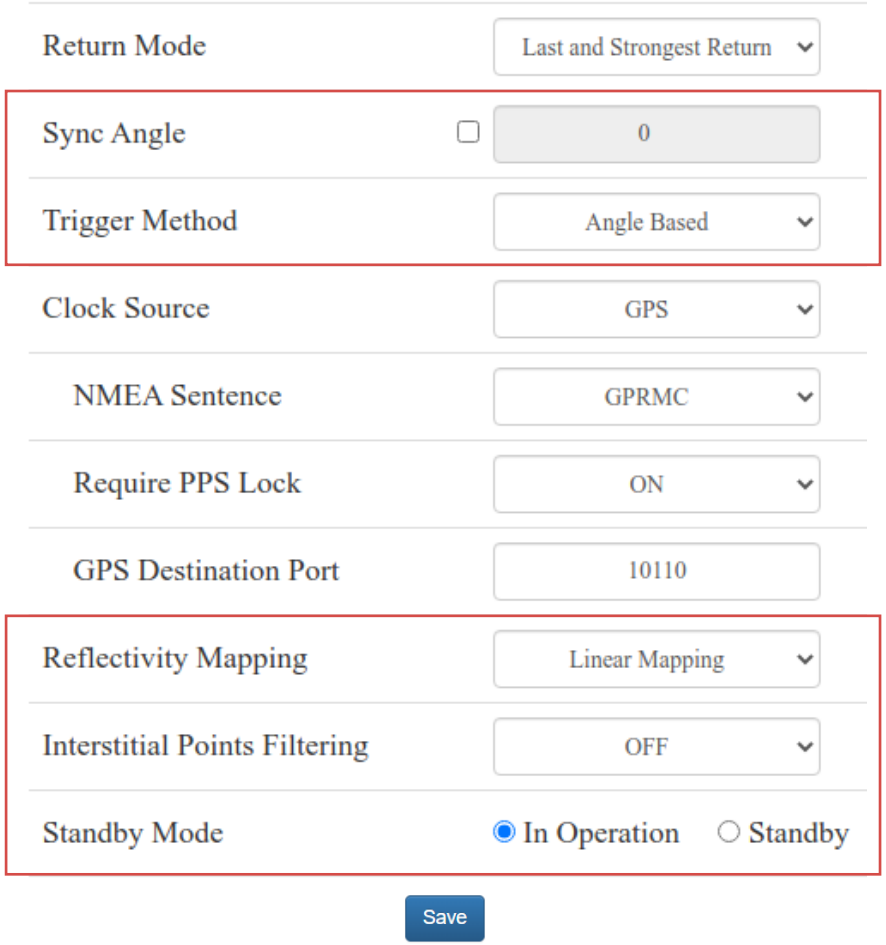
Range: except for 0.0.0.0, 127.0.0.1, and the LiDAR's IP

Mode	Destination IP
Broadcast (default)	255.255.255.255
Multicast	User-defined
Unicast	Same as the PC's IP address

4. LiDAR Functions

Spin Rate	600 rpm / 1200 rpm
Return Mode	• Single Return (Last/Strongest/First) • Dual Return (Last and Strongest, Last and First, First and Strongest)

(continued)



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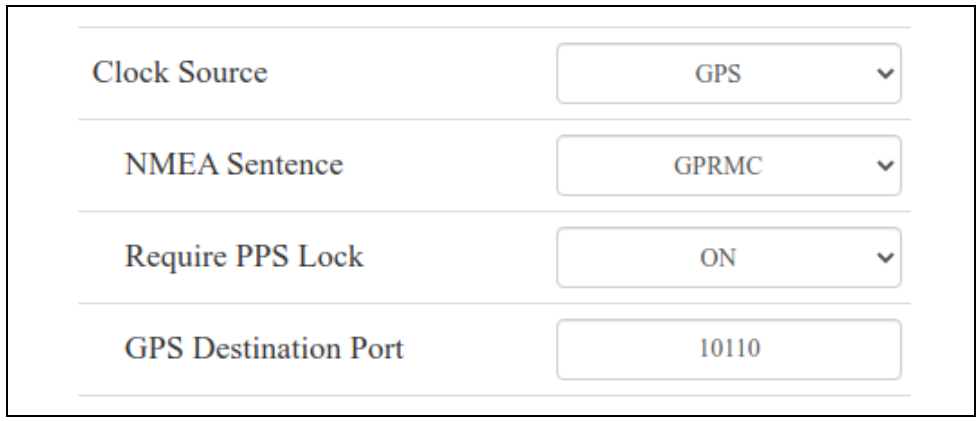
Sync Angle	0~360 degrees
	By default, the LiDAR's 0° position (see Section 1.2) is not in sync with GPS PPS or the whole second of the PTP clock. If syncing is needed, check the checkbox and input a sync angle.
Trigger Method	Angle-Based / Time-Based
	Angle-based: lasers fire every 0.09° at 5 Hz, 0.18° at 10 Hz, or 0.36° at 20 Hz. **Time-based**: lasers fire every 50 us.
Reflectivity Mapping	Linear / Nonlinear Mapping
	Linear: the 1-byte reflectivity in Point Cloud Data Packets linearly represents target reflectivity (0 to 255%). **Nonlinear**: increases the contrast in low-reflectivity region, see the appendix.
Interstitial Points Filtering	Interstitial point: 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. Such points can be mitigated.
Standby Mode	In Operation / Standby
	In Standby mode, the motor stops running and lasers stop firing.

5. Clock Source and Parameters



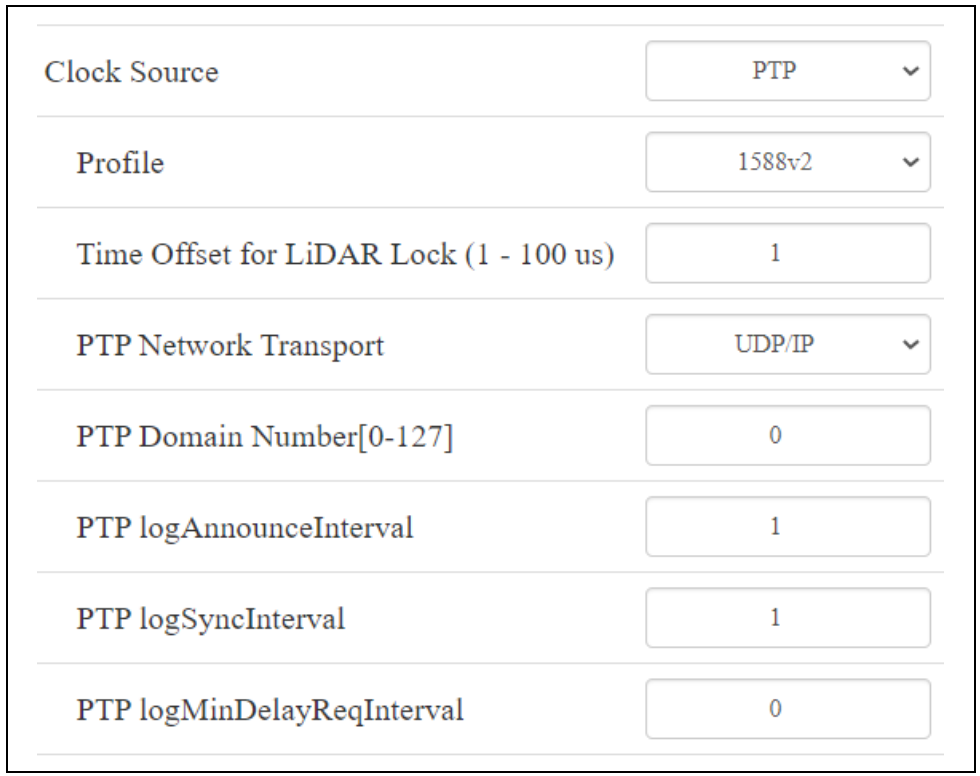
	PPS locked	PPS unlocked
NMEA locked	Update Date & Time using the current NMEA sentence. Update the µs Timestamp using the current PPS signal.	When "Require PPS Lock" is OFF, update Date & Time using the current NMEA sentence. When "Require PPS Lock" is ON, do nothing.
NMEA unlocked	Update the µs Timestamp using the current PPS signal.	Do nothing.

- Date & Time: the LiDAR's system time, accurate to the second.
- µs Timestamp: the µs part of the LiDAR's system time.

Clock Source	GPS / PTP
	In PTP mode, LiDARs do not output GPS Data Packets (see Appendix III PTP Protocol).

- When GPS is selected as the clock source:

NMEA Sentence	GPRMC / GPGGA
	Format of NMEA data received from the external GPS module, see Section 3.2.2
Require PPS Lock	When this setting is ON, PPS must be locked (in addition to NMEA being locked) when updating the LiDAR's Date & Time. • The status of both NMEA and PPS signals are shown in Section 4.1 (Home). • The complete logic is shown in the left table.
GPS Destination Port	10110 (default)
	Port used for sending GPS Data packets.



- When PTP is selected as the clock source:

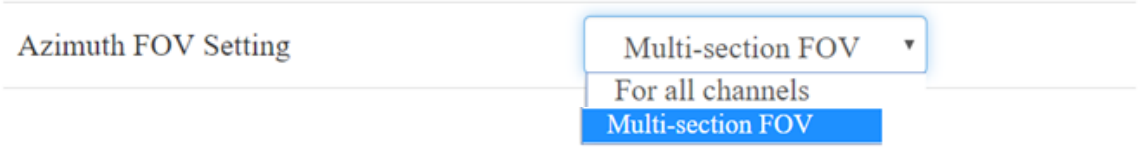
Profile	1588v2 (default) / 802.1AS
	IEEE timing and synchronization standard
Time Offset for LiDAR Lock	1 to 100 μs (integer)
	Specify the upper limit of the absolute offset between Slave and Master when the LiDAR is in PTP Locked status. See Section 4.1 (Home)
PTP Network Transport	UDP/IP (default) or L2
	1588v2: users can select UDP/IP or L2 802.1AS: only supports L2 network
PTP Domain Number	Integer from 0 to 127
	Domain attribute of the local clock

- When using the 1588v2 profile:

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

4.3 Azimuth FOV

To set the Azimuth FOV, users can select one of the two modes: for all channels, or multi-section FOV.

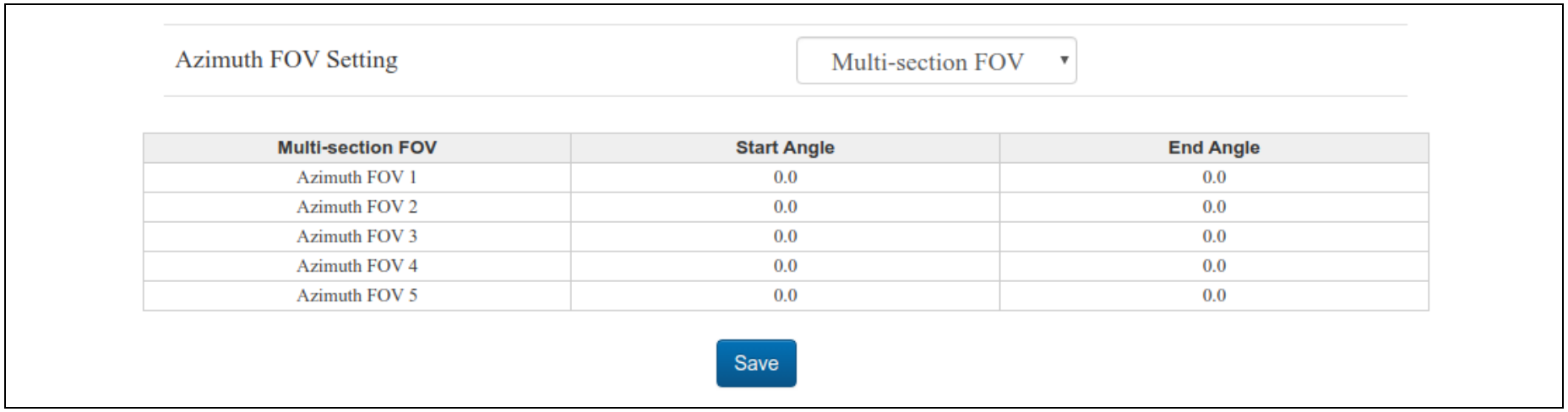


4.3.1 For all channels

A continuous angle range, specified by a Start Angle and an End Angle, will be applied to all channels.
The LiDAR outputs valid data only within the specified range.

4.3.2 Multi-section FOV

Users can configure up to five continuous angle ranges for all channels.
Each channel outputs valid data only within its specified range.



4.3.3 Note

- Click "Save" to apply your settings.
- The angles in degrees are accurate to the first decimal place.
- If the Start Angle is larger than the End Angle, then the actual azimuth FOV 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°].

4.4 Operation Statistics

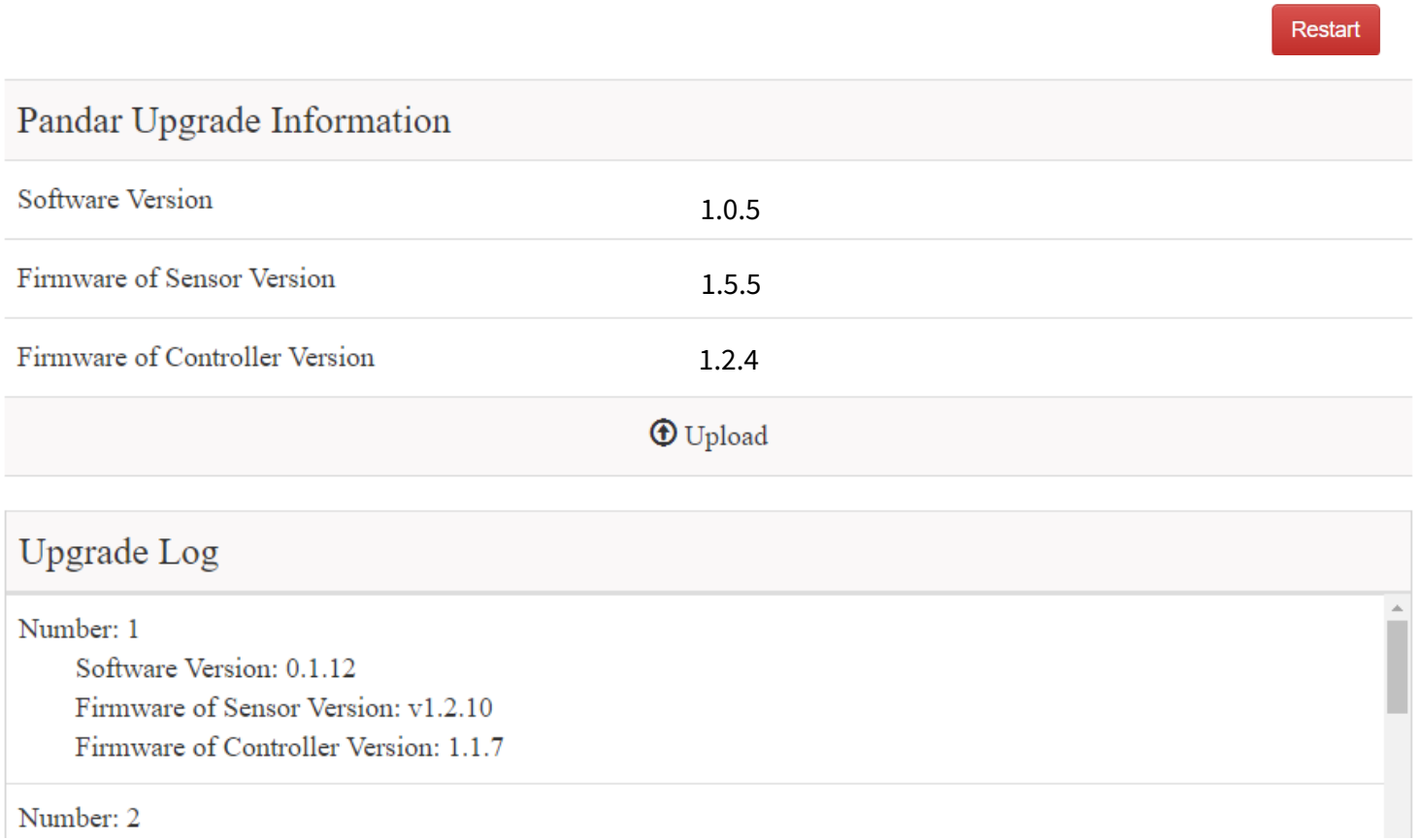
The LiDAR's operation time in aggregate and in different temperature ranges are listed.

Start-Up Counts	239
Internal Temperature	30.90℃
Total Operation Time	103 h 3 min

Internal Temperature	Operation Time
< -40 ℃	0 h 0 min
-40 to -20 ℃	0 h 0 min
-20 to 0 ℃	0 h 0 min
0 to 20 ℃	1 h 47 min
20 to 40 ℃	17 h 57 min
40 to 60 ℃	62 h 28 min
60 to 80 ℃	11 h 33 min
80 to 100 ℃	9 h 18 min
100 to 120 ℃	0 h 0 min
>120 ℃	0 h 0 min

4.5 Upgrade

The software and firmware versions described in this manual are shown in the picture below.
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.
Click the "Upload" button, select an upgrade file (provided by Hesai), 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.



A software reboot is triggered by clicking the "Restart" button on the top right corner.

Afterwards, the start-up counts in the Operation Statistics page increments by 1.

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)

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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.
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.

(Continued on the next page)

(Continued)

Symptoms	Points to Check
Can receive data on Wireshark but not on PandarView	Verify that ・ LiDAR Destination Port is correctly set on the Settings page of web control ・ PC's firewall is disabled, or that PandarView is added to the firewall exceptions ・ the latest PandarView version (see the Download page of Hesai's official website) is installed on the PC Power on again to check if the symptom persists.
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 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°C and 95°C 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

(Continued on the next page)

(Continued)

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 while the point cloud flashes, please update PandarView to the latest version (see the Download page of Hesai's official website) 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 Vertical Angles (Elevation) in the table below are design values.
The accurate values are in this LiDAR's unit's calibration 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)	0°	15°	120	50@10%
02	0°	14°	120	50@10%
03	0°	13°	120	50@10%
04	0°	12°	120	50@10%
05	0°	11°	120	50@10%
06	0°	10°	120	50@10%
07	0°	9°	120	50@10%
08	0°	8°	120	50@10%
09	0°	7°	120	80@10%
10	0°	6°	120	80@10%
11	0°	5°	120	80@10%
12	0°	4°	120	80@10%
13	0°	3°	120	80@10%
14	0°	2°	120	80@10%
15	0°	1°	120	80@10%
16 (Horizontal)	0°	0°	120	80@10%

Channel Distribution (Continued)

Channel # in UDP Data	Horizontal Angle Offset (Azimuth)	Vertical Angle (Elevation)	Instrument Range (in meters)	Range (in meters) with Reflectivity
17	0°	-1°	120	80@10%
18	0°	-2°	120	80@10%
19	0°	-3°	120	80@10%
20	0°	-4°	120	80@10%
21	0°	-5°	120	80@10%
22	0°	-6°	120	80@10%
23	0°	-7°	120	80@10%
24	0°	-8°	120	80@10%
25	0°	-9°	120	50@10%
26	0°	-10°	120	50@10%
27	0°	-11°	120	50@10%
28	0°	-12°	120	50@10%
29	0°	-13°	120	50@10%
30	0°	-14°	120	50@10%
31	0°	-15°	120	50@10%
32 (Bottom)	0°	-16°	120	50@10%

Appendix II Absolute Time and Laser Firing Time

■ Absolute Time of Point Cloud Data Packets

The Body of each Point Cloud Data Packet contains 8 data blocks, as detailed in Section 3.1.2 (Point Cloud UDP Data).

Single Return Mode

The measurements from one round of firing are stored in one block.
The absolute time of a Point Cloud Data Packet is the time when the LiDAR sends a command to trigger a round of firing that will be stored in Block 8.

Dual Return Mode

The measurements from one round of firing are stored in two adjacent blocks, see Section 3.1.2 (Point Cloud UDP Data).
The absolute time of a Point Cloud Data Packet is the time when the LiDAR sends a command to trigger a round of firing that will be stored in Blocks 7 & 8.

Calculation

The absolute time of a Point Cloud Data Packet is calculated as the sum of date, time (accurate to the second) and μs time.

- Date and Time can be retrieved either from the current Point Cloud Data Packet (6 bytes of Date & Time), or from the previous GPS Data Packet (6 bytes of Date and 6 bytes of Time).
- μs time can be retrieved from the current Point Cloud Data Packet (4 bytes of Timestamp)

 When using a PTP clock source, the LiDAR does not output GPS Data Packets.

■ Start Time of Each Block

Assuming that the absolute time of a Point Cloud Data Packet is t0, the start time of each block (the time when the first firing starts) can be calculated.

Single Return Mode

Block	Start Time (μs)
Block 8	t0 + 3.28
Block N	t0 + 3.28 - 50 * (8 - N)
Block 3	t0 + 3.28 - 50 * 5
Block 2	t0 + 3.28 - 50 * 6
Block 1	t0 + 3.28 - 50 * 7

Dual Return Mode

Block	Start Time (μs)
Block 8 & Block 7	t0 + 3.28
Block 6 & Block 5	t0 + 3.28 - 50 * 1
Block 4 & Block 3	t0 + 3.28 - 50 * 2
Block 2 & Block 1	t0 + 3.28 - 50 * 3

■ Firing Time Offset of Each Channel

Assume that the start time of Block m is T(m), $m \in \{1, 2, ..., 8\}$, then the laser firing time of Channel n in Block m is

$$t(m, n) = T(m) + \Delta t(n), n \in \{1, 2, \ldots, 32\}.$$

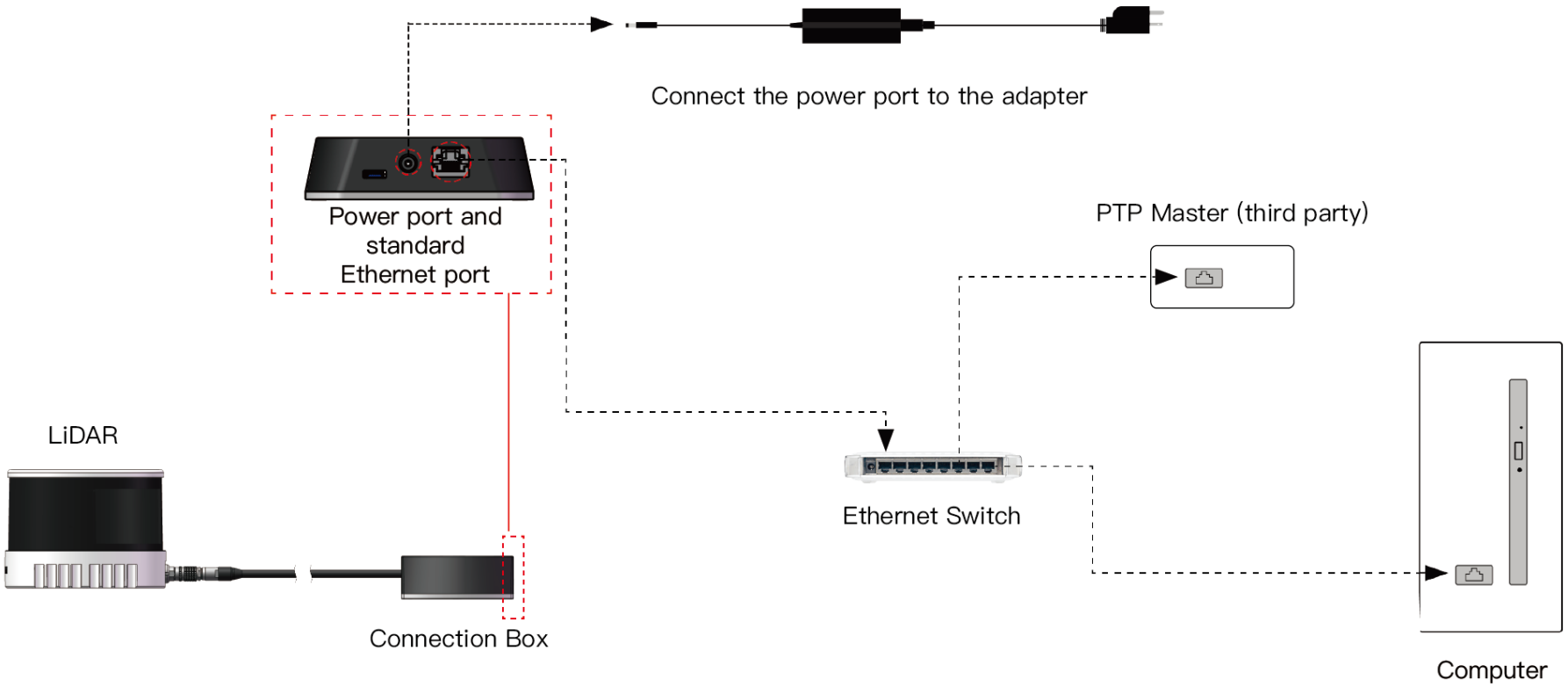
In each round of firing, the firing sequence is from Channel 1 to Channel 32. The firing time offset in units of μs:

$$\Delta t(n) = 1.512 * (n-1) + 0.28.$$

Appendix III PTP Protocol

The Precision Time Protocol (PTP) is used to synchronize clocks across a computer network. It can achieve sub-microsecond clock accuracy.

■ **LiDAR Connection When Using PTP**



■ Absolute Packing Time When Using PTP

To use PTP as the clock source, connect a third-party PTP master device to get the absolute time.

Notes

- PTP master is a third-party device and is not included with the LiDAR.
- The LiDAR works as a PTP slave device and the PTP protocol is Plug&Play.
- When using a PTP clock source, the LiDAR does not output GPS Data Packets.
- 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 Date & Time output by the LiDAR. Please verify the configuration and calibration of your PTP master device.
- If a PTP clock source is selected but no PTP master device is available, the LiDAR will count the time from an invalid past time. If a PTP clock source is supplied and later stopped, the LiDAR will continue to count the time with an internal clock.

Appendix IV Power Supply Requirements

■ Input Voltage

To ensure that the input voltage at the LiDAR's Lemo connector is 9~36 V DC, please check the specifications of the power source and the voltage drop over cables.

We recommend using 26 AWG cables, which is the thickest wire gauge supported by the LiDAR

- Define the cable length from the power source to the LiDAR's Lemo connector as L (unit: m)
- When using 26 AWG cables, the estimated cable resistance is r = 0.3L (unit: Ω)
- Define the source voltage as U_in (V). The cable voltage drop of the LiDAR operating at 10 Hz under room temperature (23±5°C) can be estimated:

$$U_{drop}(V) = \frac{U_{in} - \sqrt{U_{in}^2 - 40r}}{2}$$

Users may also estimate the cable voltage drop using the following lookup table.
When cable length exceeds 10 m, source voltage should be at least 24 V.

Estimation of Cable Voltage Drop

Cable Total Length L	Source Voltage $U_{in} = 12$ V	Source Voltage $U_{in} = 24$ V	Source Voltage $U_{in} = 36$ V
1.5 m	0.39 V	0.19 V	0.13 V
2 m	0.52 V	0.25 V	0.17 V
5 m	1.42 V	0.64 V	0.42 V
10 m	3.55 V (LiDAR's input voltage < 9 V)	1.32 V	0.85 V

When the LiDAR's input voltage approaches 36 V, make sure there is no additional overshoot in the external power system. Even a short period of overvoltage can cause irreversible damage to the LiDAR.

■ Power Consumption

The LiDAR's peak power consumption is below 30 W in all operating conditions.

- After a power-on in an ambient temperature of 0°C or below, power consumption typically remains around 15 W for a period of time.
- When setting the frame rate to 20 Hz, power consumption will also be higher than the typical value in Section 1.4 (Specifications).

In the above or similar conditions, we recommend providing at least 30 W of input power to the LiDAR.

■ Power Up/Down

During a power-up, the voltage requirements are charted in Figure IV.1

- The LiDAR's input voltage should remain under 1 V for more than 50 ms before ramping up
- During the ramp-up, the input voltage should climb to 90% of its designed value in less than 500 ms

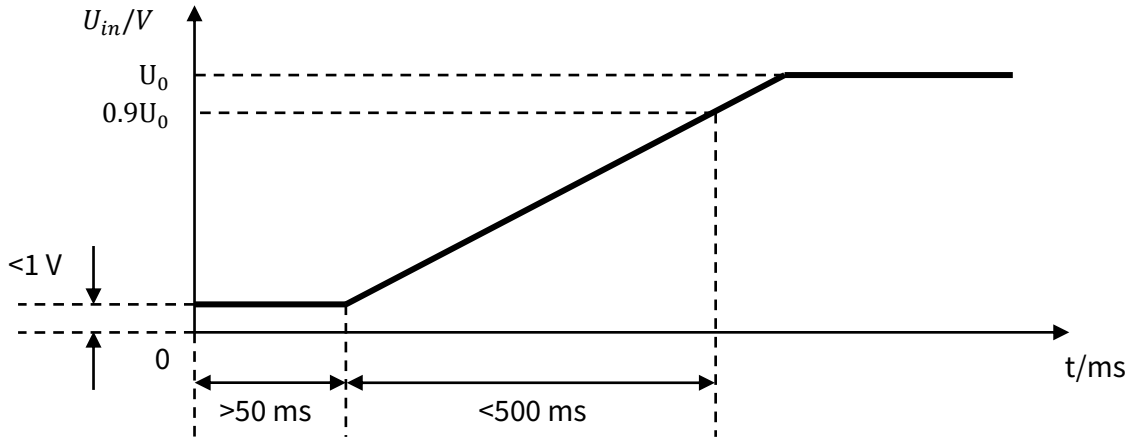


Figure 7.1 Voltage Requirements during a Power-Up

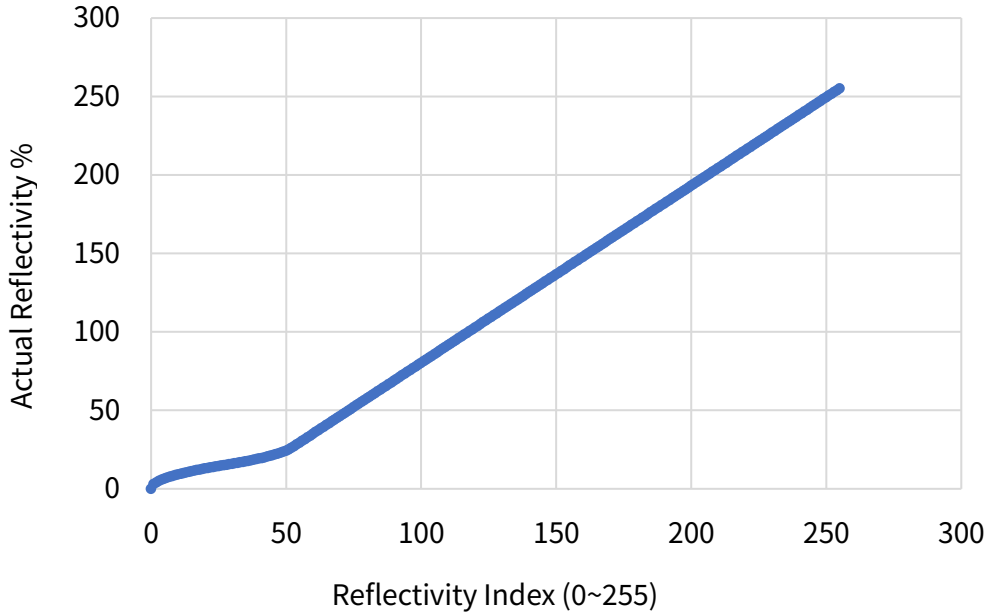
During a power-down, the LiDAR's input voltage, after dropping below 1 V, should remain for more than 50 ms before the next power-up.

Appendix V　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	12.91	40	19.2	60	34.99
1	2.89	21	13.23	41	19.59	61	36.12
2	4.08	22	13.54	42	20	62	37.25
3	5	23	13.84	43	20.43	63	38.37
4	5.77	24	14.14	44	20.87	64	39.5
5	6.45	25	14.43	45	21.34	65	40.63
6	7.07	26	14.72	46	21.84	66	41.76
7	7.64	27	15	47	22.36	67	42.89
8	8.16	28	15.28	48	22.93	68	44.02
9	8.66	29	15.57	49	23.55	69	45.15
10	9.13	30	15.86	50	24.23	70	46.28
11	9.57	31	16.16	51	25	71	47.4
12	10	32	16.46	52	25.92	72	48.53
13	10.41	33	16.77	53	27.09	73	49.66
14	10.8	34	17.09	54	28.22	74	50.79
15	11.18	35	17.42	55	29.35	75	51.92
16	11.55	36	17.75	56	30.47	76	53.05
17	11.9	37	18.1	57	31.6	77	54.18
18	12.25	38	18.45	58	32.73	78	55.3
19	12.58	39	18.82	59	33.86	79	56.43

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	57.56	100	80.14	120	102.71	140	125.28
81	58.69	101	81.26	121	103.84	141	126.41
82	59.82	102	82.39	122	104.97	142	127.54
83	60.95	103	83.52	123	106.09	143	128.67
84	62.08	104	84.65	124	107.22	144	129.8
85	63.21	105	85.78	125	108.35	145	130.93
86	64.33	106	86.91	126	109.48	146	132.05
87	65.46	107	88.04	127	110.61	147	133.18
88	66.59	108	89.16	128	111.74	148	134.31
89	67.72	109	90.29	129	112.87	149	135.44
90	68.85	110	91.42	130	114	150	136.57
91	69.98	111	92.55	131	115.12	151	137.7
92	71.11	112	93.68	132	116.25	152	138.83
93	72.23	113	94.81	133	117.38	153	139.95
94	73.36	114	95.94	134	118.51	154	141.08
95	74.49	115	97.07	135	119.64	155	142.21
96	75.62	116	98.19	136	120.77	156	143.34
97	76.75	117	99.32	137	121.9	157	144.47
98	77.88	118	100.45	138	123.02	158	145.6
99	79.01	119	101.58	139	124.15	159	146.73

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	147.86	180	170.43	200	193	220	215.58
161	148.98	181	171.56	201	194.13	221	216.7
162	150.11	182	172.69	202	195.26	222	217.83
163	151.24	183	173.81	203	196.39	223	218.96
164	152.37	184	174.94	204	197.52	224	220.09
165	153.5	185	176.07	205	198.65	225	221.22
166	154.63	186	177.2	206	199.77	226	222.35
167	155.76	187	178.33	207	200.9	227	223.48
168	156.88	188	179.46	208	202.03	228	224.6
169	158.01	189	180.59	209	203.16	229	225.73
170	159.14	190	181.72	210	204.29	230	226.86
171	160.27	191	182.84	211	205.42	231	227.99
172	161.4	192	183.97	212	206.55	232	229.12
173	162.53	193	185.1	213	207.67	233	230.25
174	163.66	194	186.23	214	208.8	234	231.38
175	164.79	195	187.36	215	209.93	235	232.51
176	165.91	196	188.49	216	211.06	236	233.63
177	167.04	197	189.62	217	212.19	237	234.76
178	168.17	198	190.74	218	213.32	238	235.89
179	169.3	199	191.87	219	214.45	239	237.02

Nonlinear Reflectivity Mapping (Continued)

Reflectivity Index (0~255)	Reflectivity (%)
240	238.15
241	239.28
242	240.41
243	241.53
244	242.66
245	243.79
246	244.92
247	246.05
248	247.18
249	248.31
250	249.44
251	250.56
252	251.69
253	252.82
254	253.95
255	255.08

Appendix VI　Legal Notice

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