

PandarXT-16

16-Channel Medium-Range Mechanical LiDAR User Manual





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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)
- This lidar product is intended as a component of an end product. It shall be evaluated in end product according to relevant standards.

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.

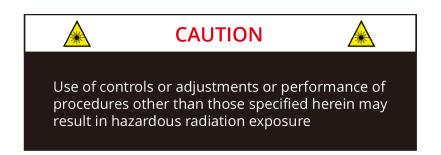


Notes: additional information that may be helpful.

Safety Notice

Special Warnings

Laser Safety





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 $23\pm5^{\circ}$ 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 PandarXT-16.

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: distance
$$d = \frac{ct}{2}$$
 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.

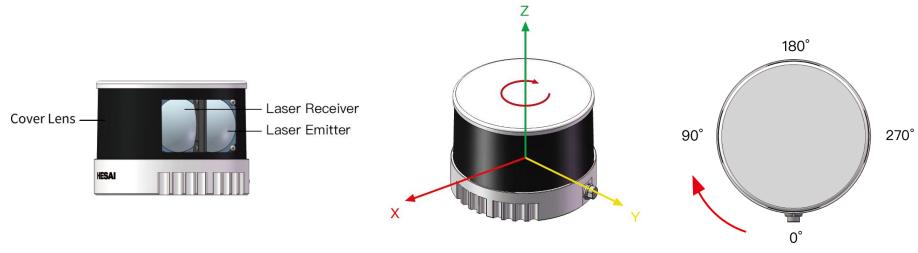


Figure 1.2 Partial Cross-Sectional Diagram

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.

Lidar azimuthal position is defined in Figure 1.4. Y-axis corresponds to 0°.

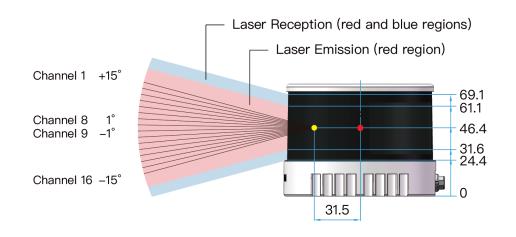
Each laser channel has an intrinsic azimuth offset. All channels is selected to define the lidar's azimuthal position.

For example, when all channels pass 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 2° across the FOV, as shown in Figure 1.5.



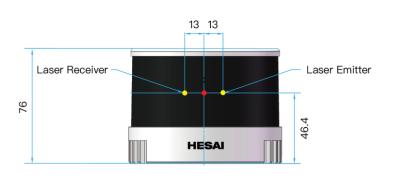


Figure 1.5 Channel Vertical Distribution

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

Each channel has an intrinsic vertical angle offset.

The offsetted angles s 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	16			
Instrument Range	0.05 to 120 m	0.05 to 120 m		
Range Capability ①	80 m @10%	80 m @10% reflectivity (Channels 5 to 12)		
	50 m @10%	(Channels 1 to 4, 13 to 16)		
Range Accuracy ②	±1 cm (typic	cal)		
	±2 cm (stan	dard)		
Range Precision ②	0.5 cm (typical, 1σ)			
	2 cm (standard)			
FOV (Horizontal)	360°			
Resolution (Horizontal)	0.09°	(5 Hz)		
	0.18°	(10 Hz)		
	0.36°	(20 Hz)		
FOV (Vertical)	30° (-15° to +15°)			
Resolution (Vertical)	2°			
Frame Rate	5 Hz, 10 Hz, 20 Hz			
Returns	Single Return (Last, Strongest, First)			
	Dual Return			

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

MECHANICAL/ELECTRICAL	_/OPERATIONAL	
Wavelength	905 nm	
Laser Class	Class 1 Eye Safe	
Ingress Protection	IP6K7	
Dimensions	Height:	76.0 mm
	Top/Bottom:	Ф100.0 / 103.0 mm
Rated Voltage Range	DC 9 to 36 V	
Power Consumption ③	9 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	
	100BASE-TX	
Measurements	Distance, Azimuth	Angle, Intensity
Data Points Generated	Single Return:	320,000 points/sec
	Dual Return:	640,000 points/sec
Point Cloud Data Rate	Single Return:	12.20 Mbps
	Dual Return:	24.40 Mbps
Clock Source	GPS / PTP	
PTP Clock Accuracy ④	≤ 1 μs	
PTP Clock Drift 45	≤1 μs/s	

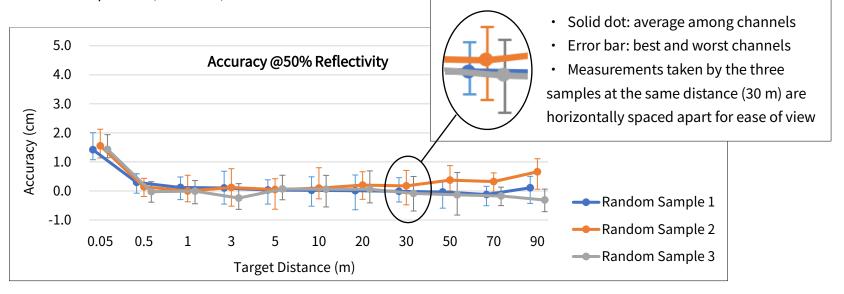
(Continued)

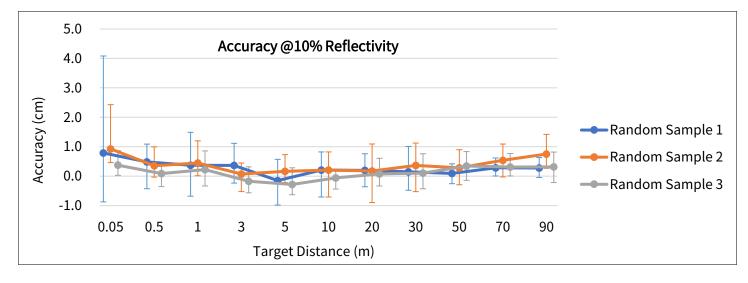
- ① Range capability: typical value
- Test conditions: 100 klux ambient illuminance, PoD (probability of detection) > 90%
- ② Range accuracy and precision
- May vary with range, temperature, and target reflectivity.
- Typical values: the average among Channels 5 to 12, measured outdoors within 0.5 to 70 m, under 30°C ambient temperature, and with a target reflectivity of 50%.
- Standard values: the average among all channels, measured in doors at 3/7/15/25 m, under room temperature, and with target reflectivities between 5% and 65%.
- 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.
- The external power supply should be able to provide at least 30 W.
- 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

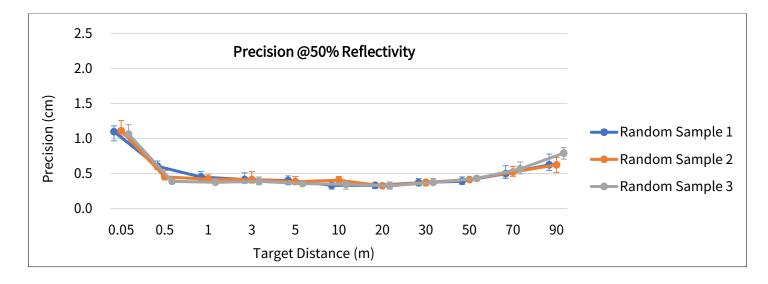
Conditions: 30°C ambient temperature, outdoors; Channels 5 to 12

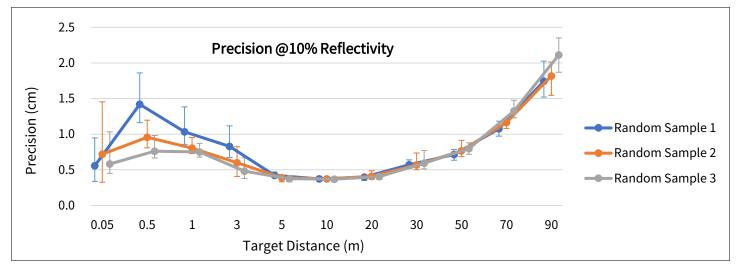




Range Precision

Definition: the standard deviation among multiple measurements, measured by a single channel Conditions: 30°C ambient temperature, outdoors; Channels 5 to 12





2 Setup

2.1 Mechanical Installation

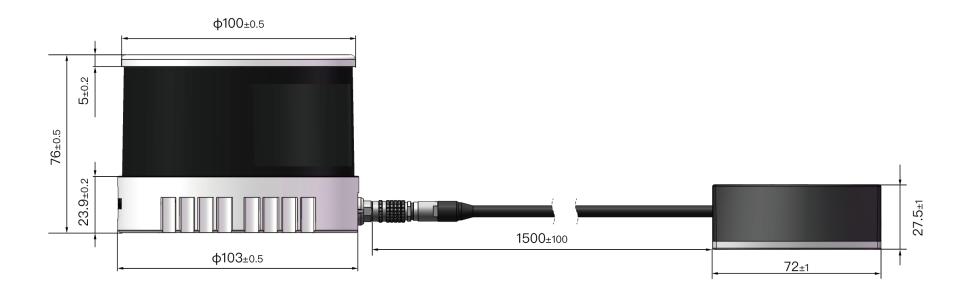


Figure 2.1 Front View (Unit: mm)

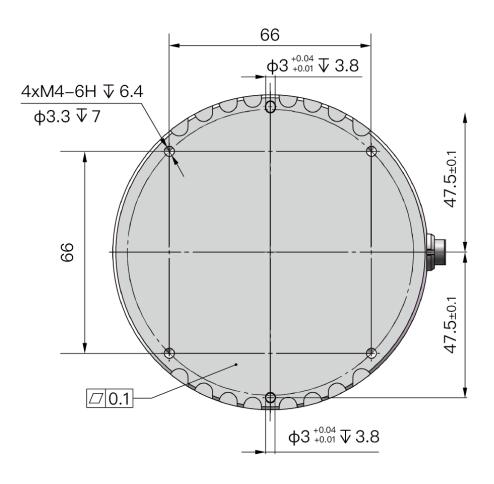


Figure 2.2 Bottom View (Unit: mm)

2.1.1 Recommended Installation

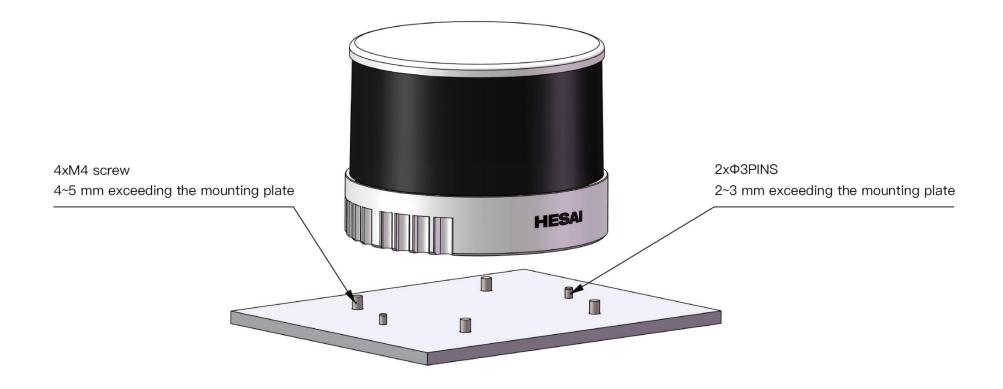


Figure 2.3 Recommended Installation

2.2 Interfaces

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

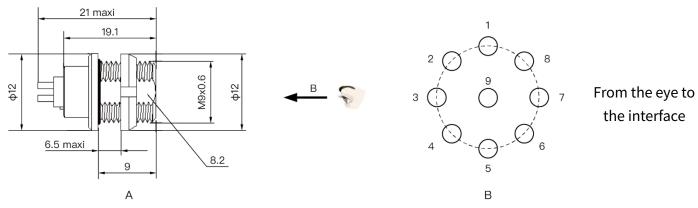


Figure 2.4 Lemo Connector (Female Socket)

2.2.1 Pin Description

Pin#	Signal	Wire Color	Voltage	Wire Gauge
1	GPS PPS	BLACK	3.3 to 12 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
"	o ignat	Wire cotor	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



Notes

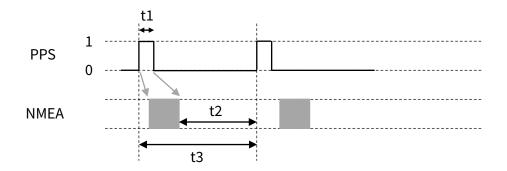
- For the GPS PPS signal, pulse width is recommended to be over 1 ms, and the cycle is 1 s (rising edge to rising edge).
- The blue wire is not used. Pin 9 may be reserved in previous batches.

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

-Ď

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



PPS cycle	t3 = 1 s \pm 50 μ s (rising edge to rising edge)	
PPS pulse width	PPS pulse width $t1 \ge 1 \text{ ms } (10 \text{ to } 100 \text{ ms recommended})$	
Timing relationship	ming 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.	

2.2.2 Cables

OD (outside diameter) = 5.0 ± 0.2 mm

Minimum bend radius: 10 * OD

2.2.3 Connector Use

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

A

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.

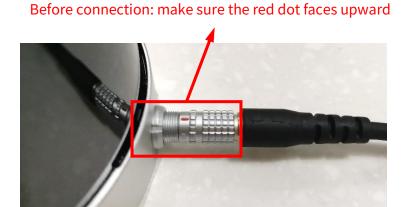


Figure 2.5 Lemo Connection



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)

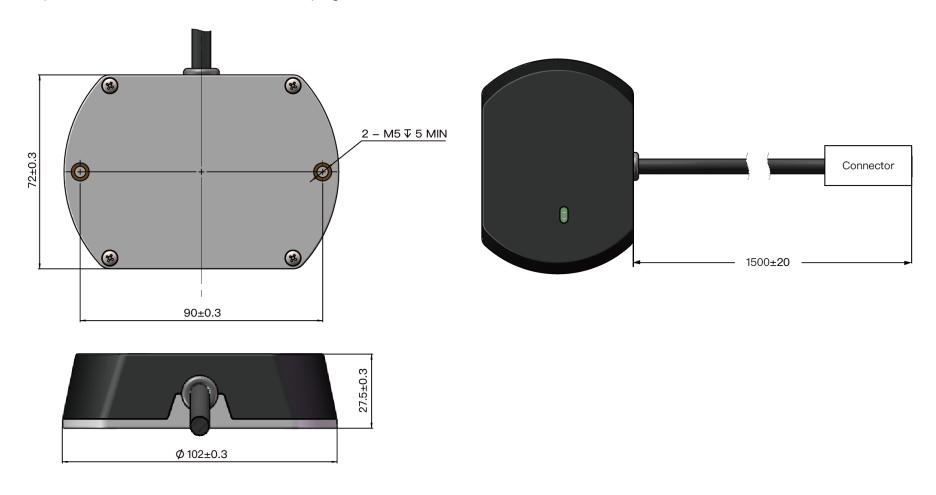


Figure 2.6 Connection Box (Unit: mm)

2.3.1 Connection Box Interfaces

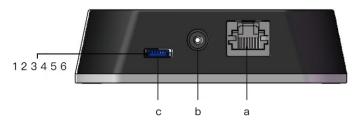


Figure 2.7 Connection Box (Front)

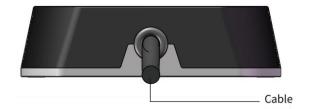


Figure 2.8 Connection Box (Back)

Port #	Port Name	Description		
а	Standard Ethernet Port	RJ45, 100 Mbps Ethernet		
b	Power Port	Connects to a DC power adapter		
С	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 12 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

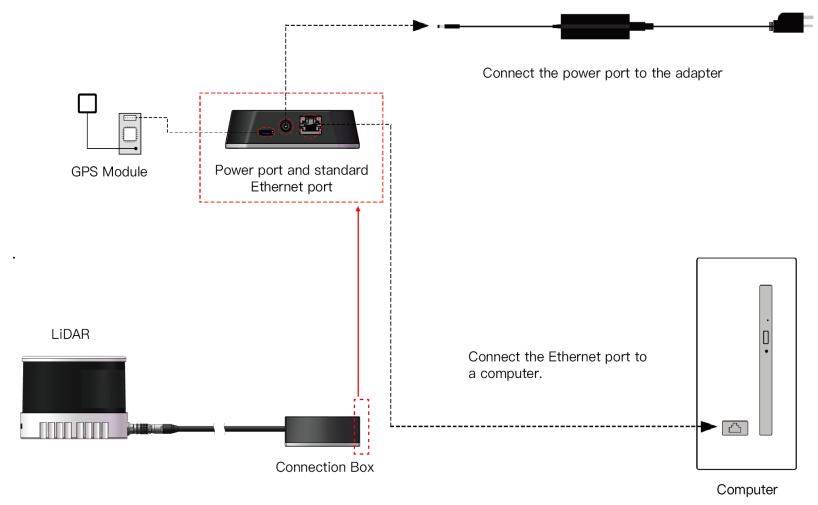


Figure 2.9 Connection Box (Connection with GPS)

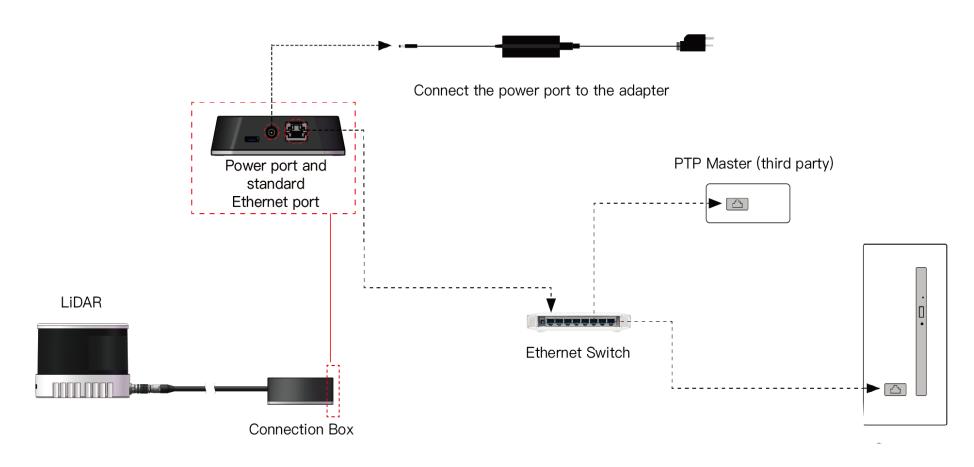


Figure 2.10 Connection Box (Connection with PTP)

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:	Open the Network Sharing Center, click on "Ethernet"
~\$ sudo ifconfig enp0s20f0u2 192.168.1.100	In the "Ethernet Status" box, click on "Properties"
(replace enp0s20f0u2 with the local Ethernet port name)	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.

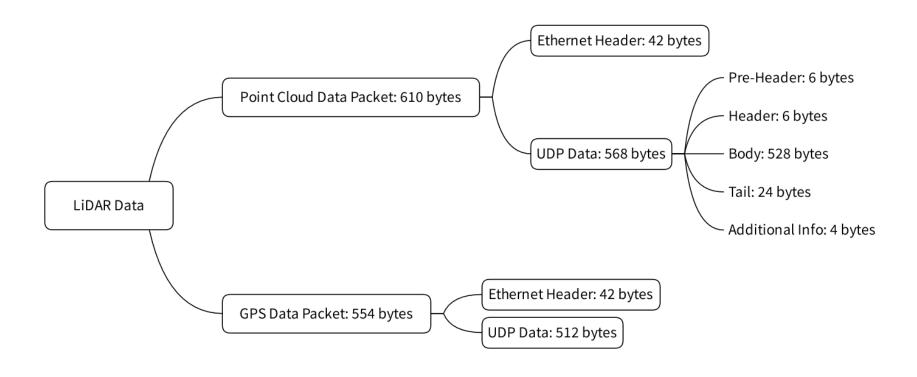


Figure 3.1 Data Structure

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)		
		Source: (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	0x0240, representing 576 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		

```
✓ Internet Protocol Version 4, Src: 192.168.1.201, Dst: 255.255.255
0100 .... = Version: 4
.... 0101 = Header Length: 20 bytes (5)

> Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
Total Length: 1108
Identification: 0x7f1d (32541)

> Flags: 0x4000, Don't fragment
Time to live: 64
Protocol: UDP (17)
Header checksum: 0xf50a [correct]
[Header checksum status: Good]
[Calculated Checksum: 0xf50a]
Source: 192.168.1.201
Destination: 255.255.255.255
```

Figure 3.2 Point Cloud Ethernet Header - Internet Protocol

3.1.2 UDP Data

■ Pre-Header: 6 bytes

Field	Bytes	Description
0xEE	1	SOP (start of packet)
0xFF	1	SOP (start of packet)
Protocol Version Major	1	Main class of the point cloud UDP packet structure
		Currently 0x06
Protocol Version Minor	1	Subclass of the point cloud UDP packet structure
		Currently 0x01
Reserved	2	-

■ Header: 6 bytes

Field	Bytes	Description	
Laser Num	1	0x10 (16 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: 528 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 16	Channel 16	Channel 16		Channel 16

Block size = size of Azimuth + 16 * size of Channel X

Each Block	n the Bo	dy: 66 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	
			- Şee 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	-	

Three single-return modes and three dual-return modes are available, see the Return Mode field in the Tail of Point Cloud UDP Data.

In a dual-return mode,

- the measurements from each round of firing are stored in two adjacent blocks (see table below);
- the Azimuth of these two blocks are the same.

Return Mode field	Odd-Number Block	Even-Number Block	Note
0x39	Last return Strongest return		If the last return is also the strongest, then the even-number block stores the
			second strongest return.
0x3B	Last return	First return	If there is only one return, then the two blocks store the same data.
0x3C	First return	Strongest return	If the first return is also the strongest, then the even-number block stores the
			second strongest return.

■ Tail: 24 bytes

Field	Bytes	Description	
Reserved	10	-	
Return Mode	1	0x33 - First Return	0x39 - Dual Return (Last, Strongest)
		0x37 - Strongest Return	0x3B - Dual Return (Last, First)
		0x38 - Last Return	0x3C - Dual Return (First, Strongest)
Motor Speed	2	Unit: RPM	

Field	Bytes	Description		
Date & Time	6	The absolute UTC time of this data packet, accurate to the second.		
		Each Byte	Range	
		Year (current year minus 1900)	≥70	
		Month	1 to 12	
		Day	1 to 31	
		Hour	0 to 23	
		Minute	0 to 59	
		Second	0 to 59	
Timestamp	4	The "µs time" part of the absolute tir	me of this data packet (defined in Appendix II)	
		Unit: μs Range: 0 to 1000000 μ	us (1 s)	
Factory Information	1	0x42		

■ 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

Take Channel 5 in Block 2 as an example:

■ Analyze the vertical angle of a data point

The designed vertical angle of Channel 5 is 7°, 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° 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

 $-\dot{Q}$ 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 2.
- Horizontal angle offset of the channel

The designed offset for Channel 5 is 0°, according to Appendix I (Channel Distribution Table).

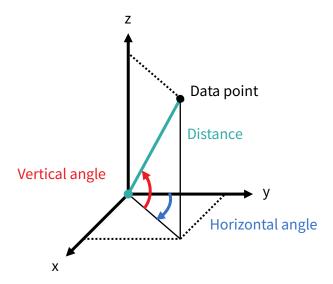
- The accurate horizontal angle offset is recorded in this LiDAR's unit's angle correction file, see Section 1.3 (Channel Distribution).
- \bigcirc Firing time angular offset of the channel = \bigcirc * \bigcirc

- 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 2
- · 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

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 the UTC time 20 05 20 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)		
		Source: (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 byt	es				
Field	Bytes	Description			
GPS Time Data 18		Header	2 bytes	0xFFEE, 0xFF first	
		Date	6 bytes	Year, month, and d	ay (2 bytes each, lower byte first) in ASCII
		Time	6 bytes	Second, minute, ar	nd hour (2 bytes each, lower byte first) in ASCII
		Reserved	4 bytes	-	
GPRMC/GPGGA Data	100	NMEA sente	nce that con	ntains date and time	
		ASCII code, v	valid till 2 by	tes after the asterisk	(*)
		The lidar car	n receive eit	her GPRMC or GPGGA	., see Chapter 4 (Web Control - Settings)
Reserved	388	388 bytes of	0xDF		
GPS Positioning	1	ASCII code, o	ASCII code, obtained from \$GPRMC or \$GPGGA		
Status					
		When \$GPF	When \$GPRMC is selected: When \$GPGGA is selected:		When \$GPGGA is selected:
		A (hex = 41) for Valid Position 0 = invalid		0 = invalid	
		V (hex = 56)	for Invalid I	Position	1 = GPS fix (SPS)
		NUL (hex =	0) for GPS b	eing unlocked	2 = DGPS fix
					3 = PPS fix
					6 = estimated (dead reckoning)
PPS Lock Flag	1	1 - locked	0 - uı	nlocked	
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

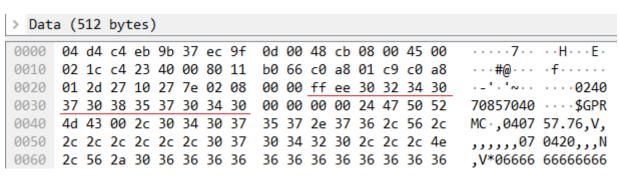


Figure 3.3 GPS Data Packet - UDP Data (Example)

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 $\,\mu$ s, 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



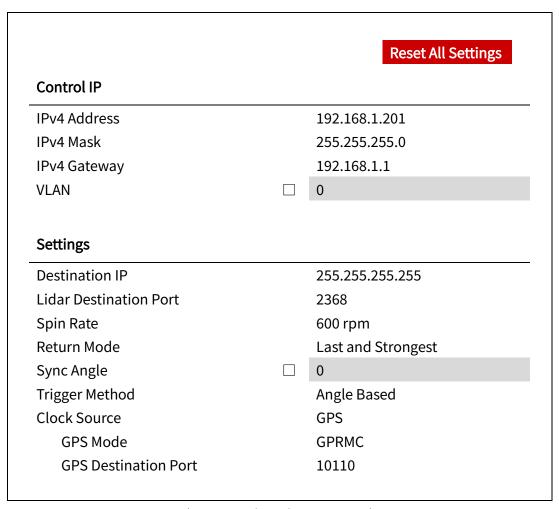
4.1 Home

Status	
Spin Rate	600 rpm
GPS	Unlock
NMEA (GPRMC/GPGGA)	Unlock
PTP	Free Run
Model	PandarXT-16
Device Info	Device Log
S/N	XTXXXXXXXXXXXXX
MAC Address	XX:XX:XX:XX:XX
Software Version	0.1.16
Sensor Firmware Version	1.2.14

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 mot	Spin Rate of the motor (rpm) = frame rate (Hz) * 60		
GPS	GPS (PPS) status			
	Lock	Lidar's internal clock is in sync with GPS PPS		
	Unlock	Not in sync		
NMEA	NMEA status			
(GPRMC/GPGGA)	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)	Frozen (Holdover) Attempting to recover the connection to the PTP master.		

4.2 Settings



(Continued on the next page)

(Continued)

Interstitial Points Filtering
Reflectivity 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	To enable VLAN tagging:		
	VLAN ID: 1 ~ 4094	Make sure the receiving host also supports VLAN.		
		Check the checkb VLAN ID).	ox and input the lidar's VLAN ID (same as the re	eceiving host's
		When VLAN is ena	the VLAN ID does not change during firmware ubled, PTP connection will be lost; when VLAN is atomatically recover.	. •
		control. To minimize s When checking th	iffers from the receiving host's, users will lose a such risks, the VLAN ID is zero (invalid value) by se checkbox, users will be alerted to input a val the checkbox, the VLAN ID will default to zero.	default. d VLAN ID.
Destination IP	Any address except for			
	0.0.0.0, 127.0.0.1, and the	Mode	Destination IP	
	lidar's IP.	Broadcast (default)	255.255.255	
		Multicast	User-defined	
	Default: 255.255.255.255	Unicast	Same as the PC's IP address	

4.2.2 Function Settings

Parameter	Options	Description
Spin Rate	600 RPM (default)	The setting spin rate is also shown on web control, see Section 4.1 (Web Control –
	1200 RPM	Home).
Return Mode	Single Return	Also shown in Point Cloud Data Packets, see the Return Mode field in Section 3.1.2
	 Last / Strongest / First 	(Point Cloud UDP Data).
	Dual Return	
	 Last and Strongest (default) 	
	 Last and First 	
	 First and Strongest 	
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	Description	
Trigger Method	Angle-Based (default)	The way laser firing	The way laser firings are triggered.	
	Time-Based	Angle-based La	asers fire every 0.09° at 5 Hz, 0.18° at 10 Hz, or	
		0.	36° at 20 Hz	
		Time-based La	asers fire every 50 μs	
Interstitial Points	OFF (default)	To mitigate the inte	rstitial points.	
Filtering	ON	Definition of interstitial points: when a beam partially hits on a front target's edge		
and further hits on a rear target, the return sig		a rear target, the return signal can result in a false point		
		located between both targets.		
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	2# Increases the contrast in low-reflectivity regions, see	
			Appendix IV (Nonlinear Reflectivity Mapping).	
Standby Mode	In Operation (default)	In Standby mode, t	he motor stops running and lasers stop firing.	
	Standby			

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)	External source of absolute time
	PTP	

■ With GPS Selected

Parameter	Options	Description	Description		
GPS Mode	GPRMC (default)	Format of the NMEA data received from the external GPS module, see Section 3.2.2 (GPS			
	GPGGA	UDP Data)	UDP Data)		
Require PPS Lock	ON (default)	When this s	When this setting is ON, PPS must be locked (in addition to NMEA being locked) when		
	OFF	updating th	updating the lidar's Date & Time.		
		The state	us of both NMEA and PPS signals	are shown in Section 4.1 (Home).	
		• The com	plete logic is shown in the table.		
			PPS locked	PPS unlocked	
		NMEA	Update Date & Time using the	When "Require PPS Lock" is	
		locked	current NMEA sentence.	OFF, update Date & Time	
				using the current NMEA	
			Update the µs Timestamp	sentence.	
			using the current PPS signal.	When "Require PPS Lock" is	
				ON, do nothing.	
		NMEA	Update the µs Timestamp	Do nothing.	
		unlocked	using the current PPS signal.		
		- Ç- Note			
		 Date & Time: the lidar's system time, accurate to the second. μs Timestamp: the μs part of the lidar's system time. 			
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)	IEEE timing a	IEEE timing and synchronization standard	
	802.1AS			
	802.1AS Automotive			
Time Offset for Lidar	1 to 100 μs (integer)	Specify the u	Specify the upper limit of the absolute offset between Slave and Master when the lidar	
Lock	Default: 1	is in PTP Locked status. See Section 4.1 (Home)		
PTP Network	UDP/IP (default)	Netword transport protocol		
Transport	L2	UDP/IP Available only for 1588v2 profile		
		L2	Available for all profiles	
Domain Number	0 to 127 (integer)	Domain attribute of the local clock		
	Default: 0			

When using the 1588v2 profile:

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

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)	Configuration mode of the azimuth FOV.
		The lidar outputs valid data only within the specified azimuth FOV ranges.
	Multi-section FOV	

- 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

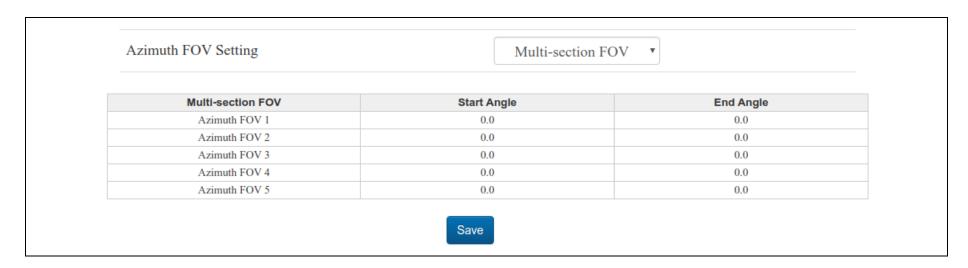
Input a Start Angle and an End Angle to form a continuous angle range.

This range applies to all channels.



4.3.2 Multi-section FOV

Input multiple (≤5) sets of Start Angles and End Angles to form multiple continuous angle ranges. These ranges apply to all channels.



4.4 Operation Statistics

These operating parameters are shown in real time:

Start-Up Counts	510	
Internal Temperature	32.10°C	
Total Operation Time	559 h 43 min	
Internal Temperature	Operation Time	
< -40 °C	0 h 1 min	
-40 to -20 °C	0 h 46 min	
···	•••	
100 to 120 °C	1 h 44 min	
>120 °C	0 h 0 min	

4.5 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	1.0.5
Firmware of Sensor Version	1.5.5
Firmware of Controller Version	1.2.4
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.

A

Warnings

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

. Ö⁻ 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			
	Mhen 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			
	Verify that			
	power adapter is properly connected and in good condition			
Indicator light is off on	connection box is intact			
the connection box	input voltage and current satisfy the requirements in Section 2.3 (Connection Box)			
	Power on again to check if the symptom persists.			
	Verify that			
	power adapter is properly connected and in good condition			
	if a connection box is used, the connection box is intact			
Motor is not running	• 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		
	Verify that		
	Ethernet cable is properly connected (by unplugging and plugging again)		
Motor is running but	Lidar's Destination IP is correctly set on the Settings page of web control		
no output data is	horizontal FOV is properly set on the Azimuth FOV page of web control		
received, neither on	firmware version of the sensor is correctly shown on the Upgrade page of web control		
Wireshark nor on	• Lidar is emitting laser light. This can be checked by using an infrared camera, an infrared sensor card, or a phone		
PandarView	camera without infrared filter		
	Power on again to check if the symptom persists.		
	Verify that		
	Lidar Destination Port is correctly set on the Settings page of web control		
Can receive data on	PC's firewall is disabled, or that PandarView is added to the firewall exceptions		
Wireshark but not on	the latest PandarView version (see the Download page of Hesai's official website or contact Hesai technical		
PandarView	support) is installed on the PC		
	Power on again to check if the symptom persists.		
	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		
Cannot open web	data packets		
control			
CONTROL	Afterwards,		
	restart PC, or connect the lidar to another PC		
	power on again to check if the symptom persists		

Symptoms	Points to Check			
Abnormal packet size (missing packets)	 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 			

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 <i>PandarView User Manual</i> (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 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 #	Horizontal Angle Offset	Vertical Angle	Instrument Range	Range (in meters)
in UDP Data	(Azimuth)	(Elevation)	(in meters)	with Reflectivity
01 (Top)	0°	15°	120	50@10%
02	0°	13°	120	50@10%
03	0°	11°	120	50@10%
04	0°	9°	120	50@10%
05	0°	7°	120	80@10%
06	0°	5°	120	80@10%
07	0°	3°	120	80@10%
08	0°	1°	120	80@10%
09	0°	-1°	120	80@10%
10	0°	-3°	120	80@10%
11	0°	-5°	120	80@10%
12	0°	-7°	120	80@10%
13	0°	-9°	120	50@10%
14	0°	-11°	120	50@10%
15	0°	-13°	120	50@10%
16 (Bottom)	0°	-15°	120	50@10%

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	Date & Time	Lidar behavior	
status	(accurate to the second)		
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.	
		- पूं- If the "Require PPS Lock" switch is ON (see Section 4.2 Web Control – Settings):	
		Only when both NMEA and PPS signals are locked will the Date & Time (accurate to the second) be	
		synchronized; otherwise, GPS signal status is deemed not good enough, and the Date & Time will	
		remain unsynchronized.	
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	Description
	(accurate to μs)	
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	Synchronized	Extract the actual date and time from the PTP Master's messages.
Locked		
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.



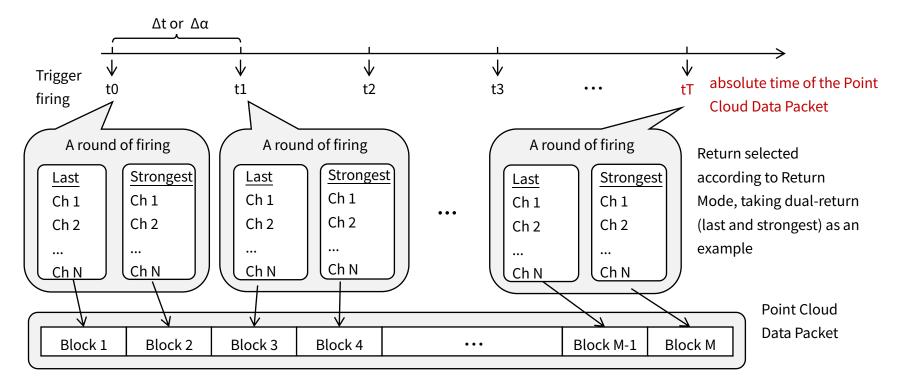
Notes

- 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.

■ Start Time of Each Block

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

Single Return Mode

Block	Start Time (μs)
Block 8	t0 + 5.632
Block N	t0 + 5.632 - 50 * (8 - N)
Block 3	t0 + 5.632 - 50 * 5
Block 2	t0 + 5.632 - 50 * 6
Block 1	t0 + 5.632 - 50 * 7

Dual Return Mode

Block	Start Time (µs)	
Block 8 & Block 7	t0 +5.632	
Block 6 & Block 5	t0 + 5.632 - 50 * 1	
Block 4 & Block 3	t0 + 5.632 - 50 * 2	
Block 2 & Block 1	t0 + 5.632 - 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 $t(m, n) = T(m) + \Delta t(n), n \in \{1, 2, \dots, 16\}.$

In each round of firing, the firing sequence is from Channel 1 to Channel 16. The firing time offset in units of µs:

$$\Delta t(n) = 3.024 * (n-1) + 0.368$$

Appendix III 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 ($23\pm5^{\circ}$ 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

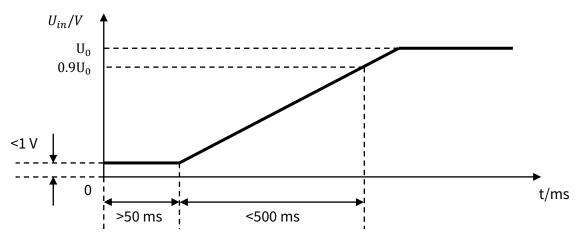


Figure IV.1 Voltage Requirements during a Power-Up

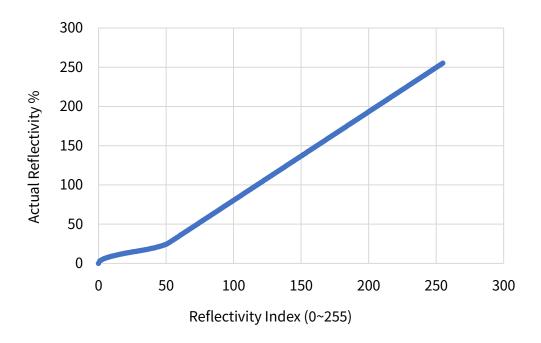
During a power-down, the lidar's input voltage, after dropping below 1 V, should remain for more than 50 ms before the next power-up.

Appendix 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	Reflectivity						
(0~255)	(%)	(0~255)	(%)	(0~255)	(%)	(0~255)	(%)
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	Reflectivity						
(0~255)	(%)	(0~255)	(%)	(0~255)	(%)	(0~255)	(%)
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	Reflectivity						
(0~255)	(%)	(0~255)	(%)	(0~255)	(%)	(0~255)	(%)
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	Reflectivity		
(0~255)	(%)		
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		

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MAP IV, Inc.

sales: contact@map4.jp

Website: https://www.map4.jp

Address: #2702 JR Gate Tower, 1-1-3 Meieki, Nakamura-ku, Nagoya



Website