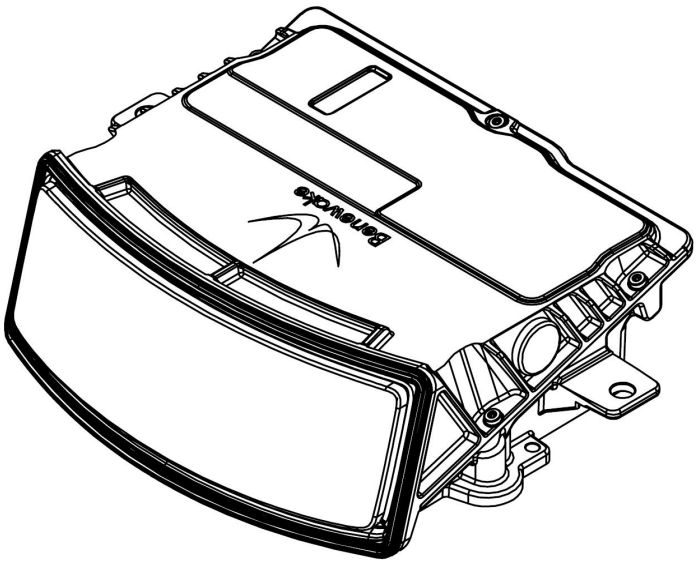
Benewake

AD2-S-X3 User Manual



Preface

This user manual contains the introduction, use and maintenance of AD2-S-X3 LiDAR. Please read this manual carefully before formal use, and strictly follow the steps described in the manual during use to avoid product damage, property loss, personal injury or/and violation of product warranty terms.

If you encounter problems that cannot be solved during use, please contact Benewake staff for assistance.

Contact Details

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Copyright Notice

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Disclaimer

The AD2-S-X3 product is constantly being improved, and its specifications and parameters will undergo iterative changes. Please refer to the official website for latest version.

Contents

Safety Warning

Before using this product, please read the contents of this manual carefully and strictly follow the relevant instructions.

Safety Precautions

Laser safety level description

- The laser safety level of this product complies with the IEC60825-1:2014 standard and is a Class 1 laser product.

Disassembly is prohibited

- ⚠ To reduce the risk of electric shock and avoid violating the warranty, please do not disassemble or modify the sensor without official authorization from Benewake, or make changes with the device software. If there is a problem with the product, please contact Benewake staff for maintenance or related technical support.

Stop usage in case of abnormality

- If any of the following situations occur, please stop using it immediately to avoid injury or damage to the product:
  - It is suspected that the product has malfunctioned or been damaged, for example: the product is found to have obvious noise or vibration
  - Feeling unwell in yourself or those around you
  - Devices in the surrounding environment started to operate abnormally

Environmental Assessment

Radio frequency interference

- Before use, please carefully read all certification and safety information on the housing nameplate. Although the product is designed, tested, and manufactured to comply with regulations regarding radio frequency energy radiation, radiation from the product may still cause other electronic equipment to malfunction.

Light interference

- Some precision optical instruments may be interfered by the laser emitted by this product, please pay attention during use.

Vibration conditions

- This product should be protected from strong vibration or mechanical shocks. If you need to obtain the mechanical shock and vibration performance parameters of this product, please contact Benewake staff for technical support.

Explosiveness and other air conditions

⚠
- Do not place or store this product near flammable and explosive materials.
- Do not use this product in any potentially explosive atmosphere, such as areas where the air contains high concentrations of flammable chemicals, vapors, or particulates (such as granules, dust, or metal powders).
- Do not expose this product to high concentrations of industrial chemicals, including easily evaporated liquefied gases (such as helium), to avoid damaging or impairing the functionality of the product.

Protection against external materials (objects)

- Please check the IP protection level in [Specifications] of this manual to avoid exposing and storing this product in an environment that exceeds the protection level.

Operating temperature

- Please check the operating temperature in [Specifications] in this manual to avoid exposing and storing this product in an environment that exceeds the operating temperature range.
- It is recommended to store this product in a ventilated and dry environment at a storage

Personnel Evaluation

Medical device interference

⚠
- Some components in this product will generate electromagnetic field. If the operator or other people in a close environment use medical equipment (such as cochlear implants, pacemakers or defibrillators, etc.), please consult the appropriate physician first. It is suggested to seek medical advice from the device manufacturer, such as whether it is necessary to maintain a certain safe distance from this product, etc.
- If you suspect that this product is interfering with your medical equipment, please stop using it immediately.

Equipment Installation and Operation

Eye safety

- This product is designed to meet Class 1 eye safety standards.
- Never look directly at the transmitted laser through a light source magnification device (such as a microscope or other form of magnifying glass).

Housing and window mirror

- This product is constructed of metal, glass and plastic and contains sensitive electronic components. Improper operations such as dropping, burning, impact or crushing will cause product damage. Once the product encounters a drop or impact, you should stop using it immediately. Please contact Benewake staff in time to obtain relevant technical support.
- This product contains high-speed rotating parts. Please do not operate it without tightening the casing.
- Avoid squeezing or making holes in this product. Once the product shell is damaged, please stop using it immediately to avoid damaging personal safety.
- To prevent product performance degradation, do not touch the LiDAR window mirror with your hands. If the window mirror is stained, please clean it according to the method described in the [Equipment Maintenance] section of this manual.
- Please avoid using hard or sharp objects to come into contact with the window mirror to avoid scratches on the window mirror. Serious scratches will affect the quality of the point cloud. If scratches have occurred, please stop using this product and contact Benewake staff for relevant technical support.

Shell high temperature

⚠

When this product is running or after running for a period of time, the shell may be at a higher temperature. In this case, please note:

- Avoid direct skin contact with the product shell to avoid burns or discomfort.
- Avoid direct contact of flammable items with the product shell to avoid causing fire.
- If this product needs to be embedded in other workwear or devices, do not cover the burn warning mark on this product. If occlusion occurs, please take other effective measures to alert third parties of high temperature risks.

Power supply and electrical interface

- Please use the connection cable and power adapter provided by Benewake to power the device. If you need to use other connection cables, please use cables that meet the power supply requirements of this product and comply with relevant safety standards.
- Do not power this product in a humid environment.
- Please disconnect the power supply before plugging or unplugging the connector. Swapping while the power is connected may cause sensor breakdown.
- Please read the [Connector] chapter in this manual and strictly follow the connector's plug and pull operation instructions. If you find any abnormalities in the interface (such as pin offset, cable damage, loose threads, etc.), please stop using it and contact Benewake staff for technical support.

Repair

- Without the official written permission of Benewake, users are strictly prohibited from dismantling, repairing or modifying this product by themselves or entrusting a third party to avoid product damage, waterproof performance failure, property loss, personal injury, and violation of product warranty terms.

1 Product Overview

This chapter mainly introduces the working principle, specifications, structural description, equipment coordinates and field of view distribution of the AD2-S-X3 LiDAR.

1.1 Product introduction

AD2-S-X3 is a high-performance automotive-grade LiDAR product with excellent 3D perception capabilities and can accurately perceive various targets.

The two-dimensional scanning system and array transceiver design adopted by AD2-S-X3 support the continuous upgrade and iteration of product performance, and also meet the needs of intelligent driving systems for continuous optimization and upgrade of perception capabilities. The ultra-high resolution of AD2-S-X3 allows it to achieve high-definition detection capabilities within the entire field of view, leaving sufficient time for the intelligent driving system to make decisions, planning and control, thereby reducing the incidence of traffic accidents and assisting intelligent driving. It assists vehicles in making them safer and smarter.

1.2 Working principle

- The ranging principle is Time of Flight (ToF):
  - ❖ The laser transmitter emits an ultrashort laser pulse;
  - ❖ The laser is projected onto the object, diffuse reflection occurs, and the laser receiver receives the diffuse reflected light;
  - ❖ By measuring the flight time of the laser beam through space, the distance from the target object to the sensor can be accurately calculated.

$$d = \frac{ct}{2}$$

d：distance　c：speed of light　t：flight time of laser beam

- The principle of angular direction measurement is to use the internal scanning device of the sensor to deflect the emitted laser beam, trigger the measurement with a regular angular amplitude to scan the surrounding environment, and realize the perception of the three-dimensional environment.

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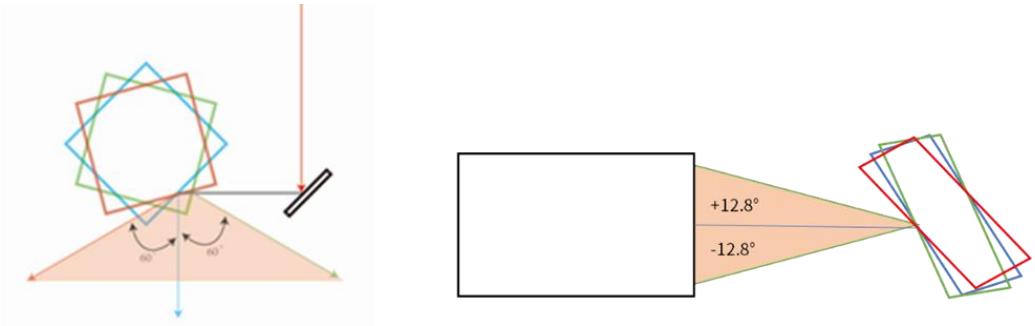

Figure. 1: Schematic diagram of scanning mechanism

1.3 Specifications

Performance parameters	
Detection range	200m@10% reflectivity
Blind zone ①	≤0.5m
Field of view (H x V)	120° x 25.6°
Angular resolution (H x V)	0.2° x 0.1°
ROI field of view (H x V)	120 ° x 8°
ROI angular resolution (H x V)	0.1° x 0.1°
Ranging accuracy ②	5cm @1σ
Frame rate	10Hz
Frequency	2.016 M points/s (including ROI)
Echo mode	Single echo & double echo
Equivalent lines	256
Laser performance	
Laser wavelength	905nm
Laser safety level	Class 1 Eye-safe [IEC60825-1：2014]
Data transmission	
Data interface	1000Base-T1 automotive grade Ethernet

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Data transmission protocol	UDP/TCP
Time synchronization	gPTP, PTP, NTP
Work platform	Windows, Linux (Ubuntu) & ROS drivers
Mechanical/Electrical	
Power consumption	≤15W
Operating Voltage	9~32V
Operating temperature	-40℃ ~ +85℃
storage temperature	-40℃ ~ +105℃
Device Dimensions (H x W x D)	49 x 160 x 144mm
weight	≤1.2Kg
Device interface	Tyco 2446023-1
Protection level	IP67&IP6K9K

① The measurement blind zone is measured under outdoor lighting conditions of less than 100 Klux. Any changes in environmental conditions may cause changes in the measurement results.
② The measurement accuracy is based on the ambient temperature of 25°C and may change due to various factors such as ranging, reflectivity, and environmental conditions.

1.4 Structural Appearance

AD2-S-X3 uses aluminum alloy enclosure and a curved glass window at the front. The overall appearance of the LiDAR is as shown in the figure below:

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Figure. 2: AD2-S-X3 Appearance

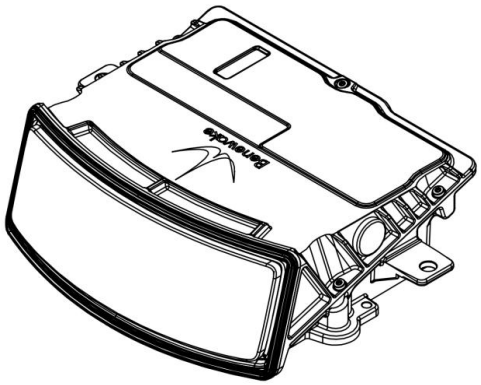

Figure.3: AD2-S-X3 Sensor view

1.5 Coordinates System and Field of View Distribution

1. Device coordinate system

The coordinate system of AD2-S-X3 is shown in the figure below. The positive direction of the X-axis is the direction of the LiDAR window glass, the positive direction of the Z-axis is perpendicular to the bottom surface and upward, and the positive direction of the Y-axis is parallel to the direction of the rear housing of the device; the XYZ axis constitutes a right-handed coordinate system, and the origin of the LiDAR coordinates is located at the center of the LiDAR window glass. The output point cloud data is based on the LiDAR coordinate origin.

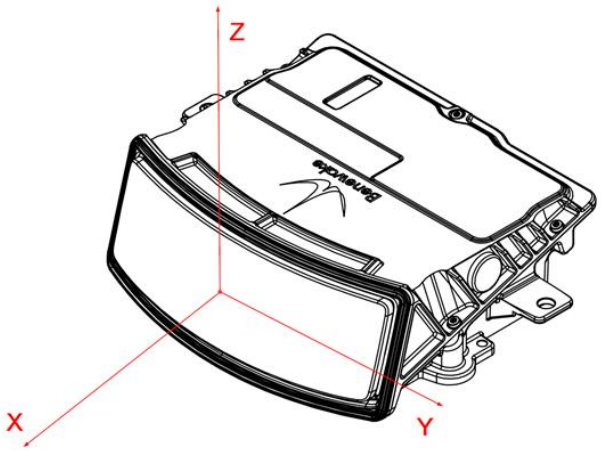

Figure. 4: Schematic diagram of AD2-S-X3 LiDAR coordinate system

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2. Horizontal field of view distribution

The horizontal field of view of AD2-S-X3 is 120°, with the positive X-axis direction as the center line, and the left and right sides are 60°. The horizontal field of view angle distribution is shown in the figure below:

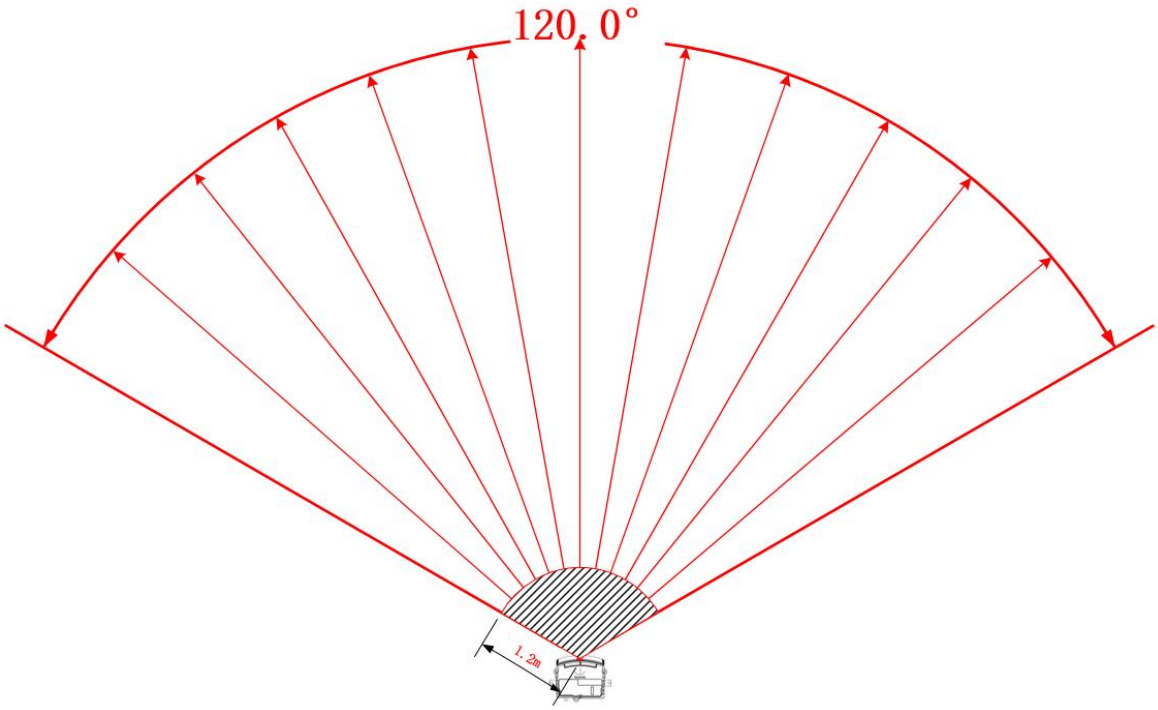

Figure. 5: AD2-S-X3 horizontal field of view angle distribution

3. Vertical field of view distribution

The vertical field of view is 25.6°, equivalent to 256 wires, evenly distributed. The specific vertical field of view angle distribution is shown in the figure below:

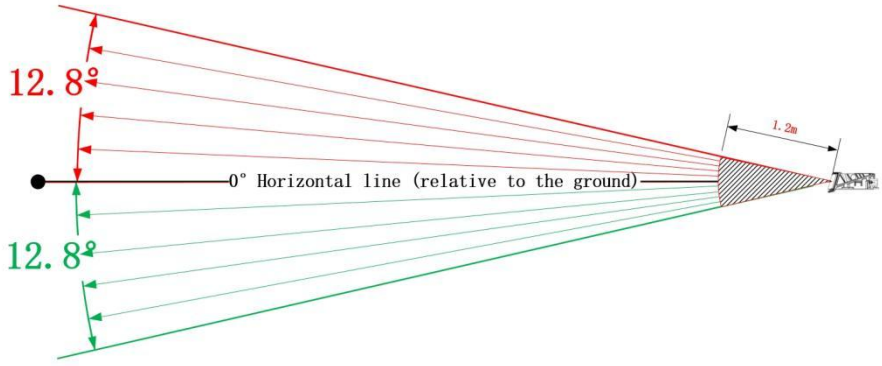

Figure. 6: Schematic diagram of vertical field of view angle distribution of AD2-S-X3

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2 Device Installation

This section introduces the device size, mechanical installation, converter box (optional), connection and other information of AD2-S-X3 LiDAR.

2.1 Equipment size

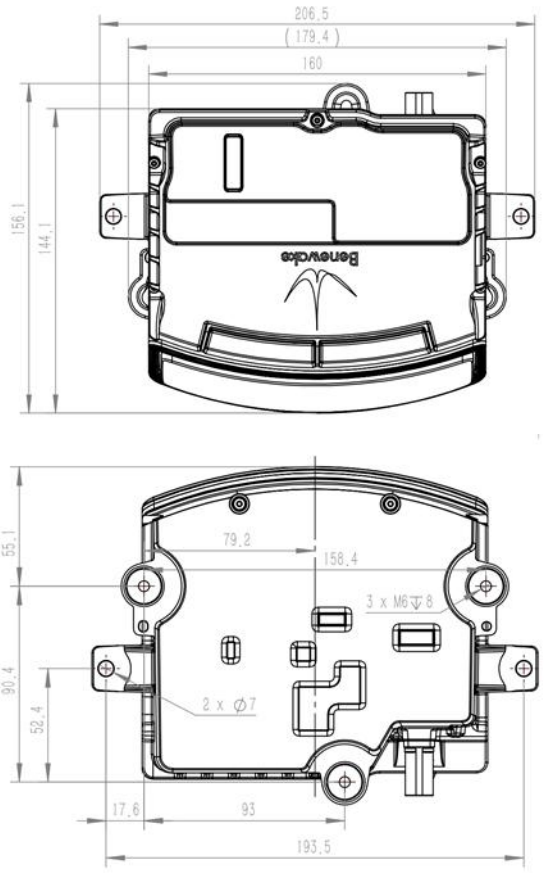

Figure. 7: Top view (left) & bottom view (right) of the sensor (unit: mm)

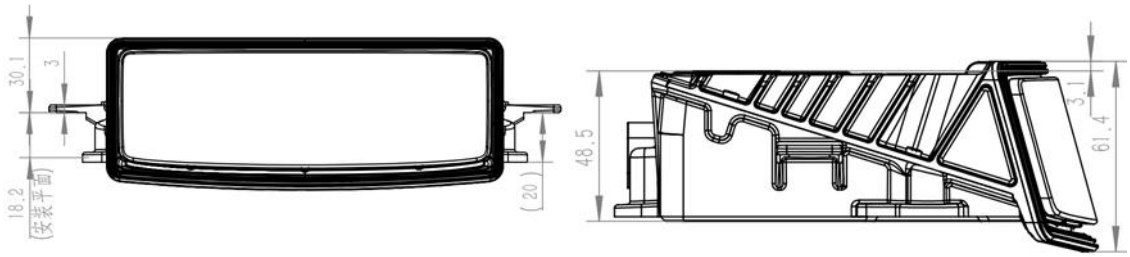

Figure. 1Front view (left) & side view (right) of the equipment (unit: mm)

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2.2 Mechanical installation

AD2-S-X3 has three M6 installation holes reserved, as shown in the red circle of the following figure. You can fix the sensor on the working platform through the reserved holes.

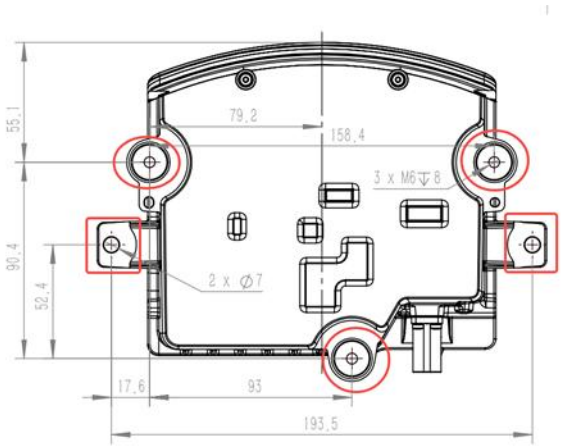

Figure. 9: Diagram of AD2-S-X3 sensor installation hole locations

Precautions:

- Make sure the device is leveled during installation.
- Confirm whether the device is installed securely and check whether there is any obstruction in front of the window glass.
- During installation, if any parts are damaged or missing, please contact Benewake technical support team.

2.3 Converter box (optional)

When testing the device, a converter box needs to be used to connect the computer and equipment to complete power supply and data transmission. The converter box is equipped with a standard industrial Ethernet interface and a power interface, and supports 9~32V DC power supply.

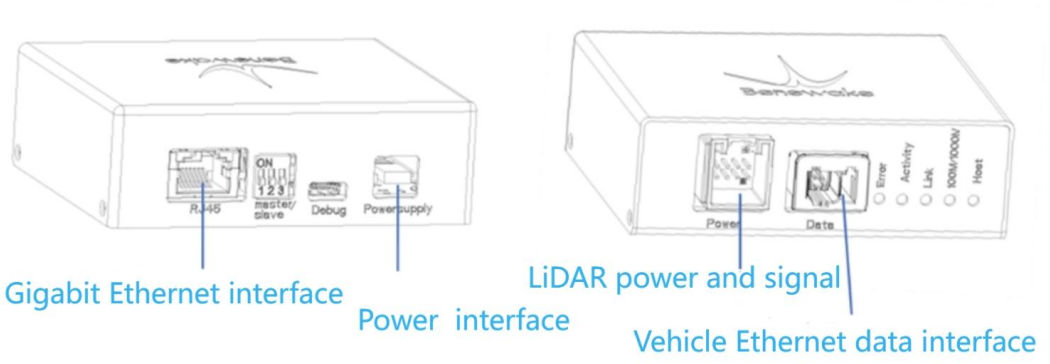

Figure. 2: AD2-S-X3 adapter box

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Table. 1Adapter box interface description table

Interface name	Specification	Definition
Power supply interface	DC Jack 2.5mm	12V power supply
Gigabit Ethernet network interface	RJ45	Device data transfer
Vehicle Ethernet data interface	Board connector: 2304372-1	Device data transfer
LiDAR power and signal	Board connector: 2311621-1	Connect LiDAR

2.4 Connector

2.4.1 LiDAR terminal connector

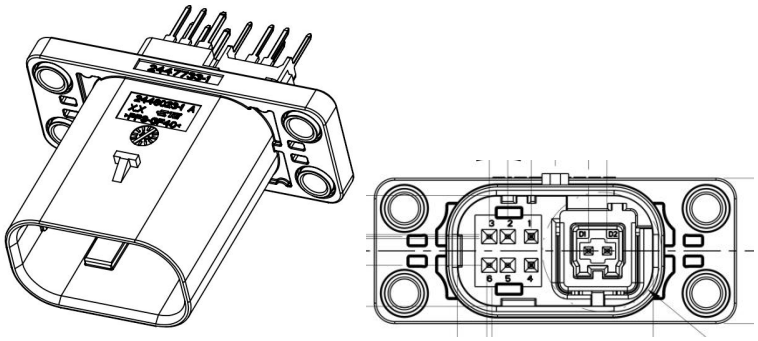

Figure. 3LiDAR connector appearance & interface size

Table. 2: Interface connector pin definitions

Pin number	Signal	Non-vehicle customer	level
1	KL15	VCC12V	9~16V
2	NC	NC	9~16V
3	NC	NC	—
4	GND	GND	0V
5	NC	NC	—
6	NC	NC	—
D1	ETH_MDI-N	ETH_MDI-N	—
D2	ETH_MDI-P	ETH_MDI-P	—

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2.4.2 Connector plugging and unplugging

- Plugging: After powering off, insert the red pin on the cable end into the connector lock on the LiDAR end. When you hear a click, the connection is successful.
- Unplugging: After powering off, slightly pull up the red safety pin, and then press the black bayonet to pull out the wire end connector.

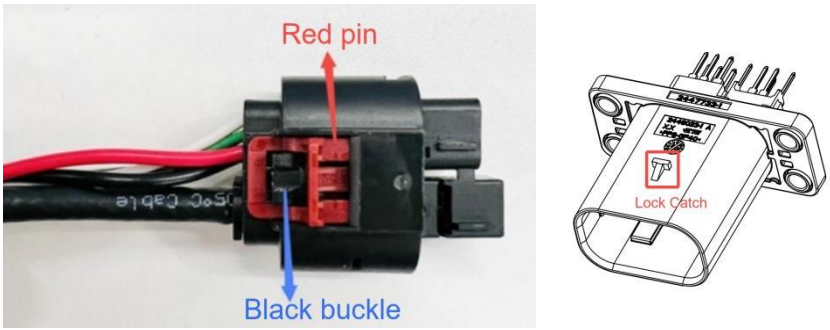

Figure. 4Connector plugging & unplugging

Precautions:

- Do not pull out the cable connector with strong force or twist the connector to avoid damage to the connector pins.
- It is not advised to assemble cable connector shells and cable clamps by the customer.
- It is prohibited to connect cable connectors without shells to avoid damaging the internal circuit of the LiDAR.

2.4.3 LiDAR connection

An additional Ethernet hybrid harness is required between the LiDAR and the junction box. As shown in the picture below: the left side is the LiDAR end, and the right side is the converter box end.

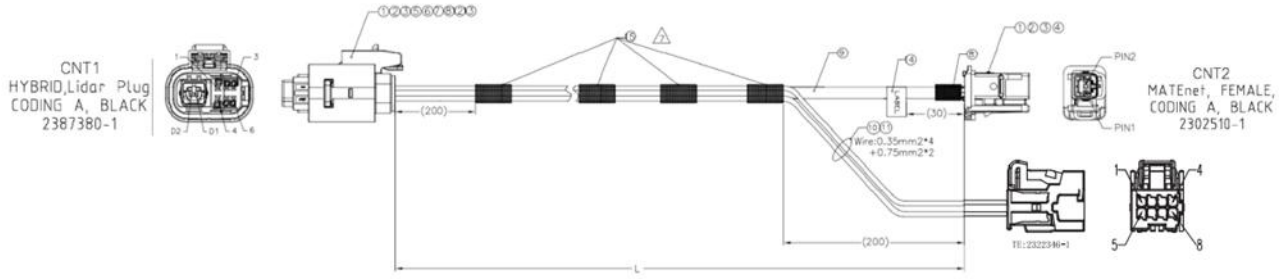

Figure. 5Schematic diagram of supporting Ethernet hybrid wiring harness

The connection method between LiDAR, computer and junction box is as shown in the figure below:

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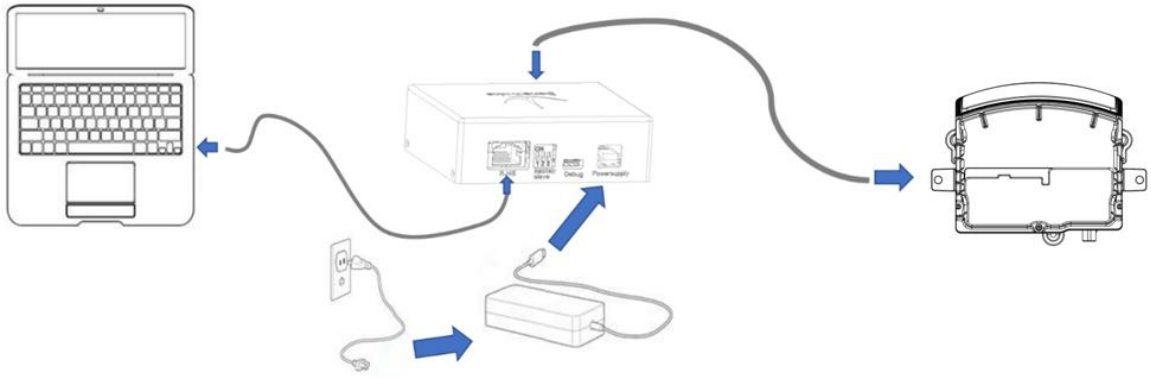

Figure. 6LiDAR connection diagram

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3 Sensor Usage

This chapter mainly introduces the GUI software point cloud viewing and communication protocols of the AD2-S-X3 LiDAR.

3.1 Point cloud viewing

The sensor does not contain any power switch. Data can be transmitted after the power adapter is connected and connected to the computer via a network cable.

Before receiving data, please check whether the IP address of the computer you are using is in the same network segment as the device; if not, the computer IP needs to be configured. Users can use the Benewake LiDAR Viewer debugging software to record and play back point cloud data. This debugging software has a total of two methods for device connection:

1. If the device IP and port number are known, you can click the Add button to connect to the device.
2. If the device IP and port number are not clear, click the icon to automatically search for the device. Wait for about 5 seconds, and the information of the connected device will be displayed on the device management panel.

Click **start** button in the device management panel and wait a moment to obtain the point cloud data; click the **stop** button to stop the LiDAR from working, and the point cloud data will stop updating.

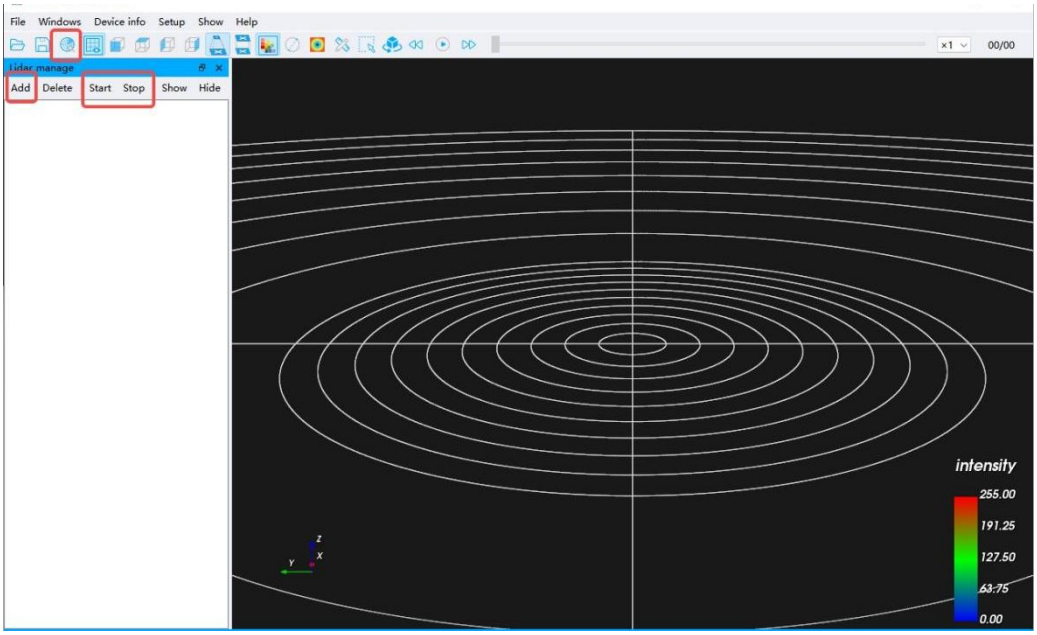

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Figure. 15: Connecting device to GUI software

If you want to know more about how to use the Benewake LiDAR Viewer debugging software, you can contact Benewake technical team to obtain the usage instructions of the software.

3.2 Parsing protocol

The LiDAR sensor and the debugging computer communicate through Ethernet. The interface protocol type is: UDP Server. The communication content is divided into three types: **MDOP**, **DCSP** and **DSOP**. The default factory setting is fixed IP and port number mode. The protocols list is as follows:

Table. 3: Communication protocol table

Protocol name	Protocol Type	Default IP address	Broadcast type	Description
MDOP	UDP	192.168.0.2	Unicast	Main Data Communication Protocol
DCSP	UDP	192.168.0.2	Unicast	Device Command Set Protocol
DSOP	UDP	192.168.0.2	Broadcast	Device Status Protocol

3.2.1 Master Data Communication Protocol (MDOP)

Description:

- Main data communication protocol: MDOP stands for Main Data Output Protocol.
- Mainly responsible for outputting three-dimensional measurement related data: laser ranging values, reflectivity, horizontal azimuth angle, vertical azimuth angle, and timestamp offset relative to the frame header.
- The output data is of I/O type and is transmitted to the debugging computer for analysis and point cloud data is formed.
- In **single echo mode**, the MAC frame size is 954 Bytes: MAC frame header 42 Bytes, protocol header 42 Bytes, data block 864 Bytes, and frame tail is 6 Bytes. The theoretical data transfer rate is approximately **68.688 Mbps**;
- In **dual echo mode**, the MAC frame size is 906Bytes: MAC frame header 42 Bytes, protocol header 42 Bytes, data block 816 Bytes, and frame tail is 6 Bytes. The theoretical data transfer rate is approximately **130.464 Mbps**.

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The basic structure of the main data communication protocol is as follows:

Table. 4: Basic structure of master data communication protocol

Field	Header	Payload	Tail
Number of bytes (Bytes)	42	N (variable)	6
Description	Frame header	Load	End of frame
Remarks: • All Reserve bytes are padded with 0x00 • All multi-byte combination values are transmitted in little-endian mode (that is, the low bit is transmitted first, then the high bit)			

a) MDOP header

A total of 42 Bytes, mainly used to identify the data starting position, product version, protocol type, packet count, frame number, etc.; the detailed structure is shown in the table below:

Field	Offset (Bytes)	Number of bytes (Bytes)	Value	Description
SOF	0	2	"BW"	Start tag, fixed value
Product Identifier	2	1	0x01: AD2-S-X3	Product version
Protocol Identifier	3	1	0x00: Data transfer protocol MDOP	Protocol type
Protocol Version	4	2	0x0001	Protocol version
Count	6	4	0x0000	● Packet count value ● Unsigned integer ● Sequential count value ● Add 1 each time, and start counting from 0 again when overflow occurs.
nFrame	10	2	/	● Frame number ● Unsigned integer ● Sequential count value ● Add 1 each time, and start counting from 0 again when overflow occurs.
nLine	12	2	/	● Line number (one glow) ● The number of rows of the data block in the payload [one row actually contains 16 channels, nLine starts from 0]
Points	14	2	/	Points in the packet
Timestamp_s	16	8	/	Timestamp – whole second
Timestamp_ns	24	4	/	Timestamp – nanoseconds
Return mode	28	1	0x00: First echo	Echo mode

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			0x01: Strongest echo 0x02: Last echo 0x03: Double Echo: Strongest + Last 0x04: Double echo: First + Last 0x05: Double Echo: First + Strongest	
Center Coordinate of ROI-X Direction	29	2	Non-0xFFFF: Horizontal direction (X direction) ROI area center point coordinates 0xFFFF: ROI function is turned off	The effective center point angle of the ROI area in the horizontal direction (X direction) is rounded to the nearest ten times
Center Coordinate of ROI-Y Direction	31	2	Non-0xFFFF: Vertical direction (Y direction) ROI area center point coordinates 0xFFFF: ROI function is turned off	The effective center point coordinate of the ROI area in the vertical direction (Y direction) is rounded to an integer ten times
Width of ROI-Region	33	2	Non-0xFFFF: Valid angle range of horizontal ROI area 0xFFFF: ROI function is turned off	The effective angle range of the horizontal ROI area is rounded to ten times
Height of ROI-Region	35	2	Non-0xFFFF: Valid angle range of vertical ROI area 0xFFFF: ROI function is turned off	The effective angle range of the ROI area in the vertical direction is rounded to ten times
Reserve	37	5	/	reserve

Note:

- Protocol version: Use CRC verification.
- The number of points in the Points packet: the payload contains data generated by how many times the light is emitted.
- Description of the data contained in point and payload:
  - A UDP transmission contains a fixed number of data blocks, 4 data blocks for Cartesian coordinates and 12 data blocks for spherical coordinates (the specific format of the data block is described later).
  - For single echo, one light emission produces 1 data block; for double echo, one light emission produces 2 data blocks.
  - For one UDP transmission, for Cartesian coordinates, a single echo can transmit data generated by up to 4 luminescences (points <= 4) each time; Dual echo can transmit data generated by a maximum of 2 luminescences (points <= 2) each time.

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- ❖ For one UDP transmission, for spherical coordinates, a single echo can transmit up to 12 luminous data (points <= 12) each time; a double echo can transmit up to 6 luminous data (points <= 6) each time.
- ❖ If the points are less than the maximum number of times of light emission that can be transmitted, the remaining payload is filled with 0.
- ❖ If it is encoder data, it represents the number of data transmission points in this frame. Each point contains 12 bytes, not exceeding 76.

b) MDOP payload

It is the measurement data part in the protocol package. In the single echo mode, there are **864 Bytes** in total, which are composed of single-echo data generated by **12 luminescences**. The data block size generated by each light emission is **72 Bytes**. In dual-echo mode, there are **816 Bytes** in total, which are composed of dual-echo data generated by **6 luminescences**. The data block size generated by each light emission is **136 Bytes**. See the table below for detailed structure:

	Segmentation	Field	Offset (Bytes)	Number of bytes (Bytes)	Description
Single Luminescence Data	Share Field	h_azimuth	0	2	Horizontal azimuth angle: -60° ~ +60°; resolution: 0.2°
		v_azimuth	2	2	Vertical azimuth angle: -12.8° ~ +12.8°; resolution: 0.1°
		time_offset	4	4	Timestamp offset relative to frame header
	Echo 1	ch1_distance	8	2	Channel 1 distance; accuracy: 1cm
		ch1_Intensity	10	1	Channel 1 reflectivity
		ch1_reserved	11	1	The lower 2-bits are used as confidence, the other bits are reserved
		ch2_distance	12	2	Channel 2 distance; accuracy: 1cm
		ch2_Intensity	14	1	Channel 2 reflectivity
		ch2_reserved	15	1	The lower 2-bits are used as confidence, the other bits are reserved
		...			
		ch16_distance	68	2	Channel 16 distance; accuracy: 1cm
		ch16_Intensity	70	1	Channel 16 reflectivity
		ch16_reserved	71	1	The lower 2-bits are used as confidence, the other bits are reserved
	Echo 2 (Dual echo only)	ch1_distance	72	2	Channel 1 distance; accuracy: 1cm
		ch1_Intensity	74	1	Channel 1 reflectivity
		ch1_reserved	75	1	The lower 2-bits are used as confidence, the other bits are reserved
		ch2_distance	76	2	Channel 2 distance; accuracy: 1cm
		ch2_Intensity	78	1	Channel 2 reflectivity
		ch2_reserved	79	1	The lower 2-bits are used as confidence, the other bits are reserved
		...			

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		ch16_distance	132	2	Channel 16 distance; accuracy: 1cm
		ch16_Intensity	134	1	Channel 16 reflectivity
		ch16_reserved	135	1	The lower 2-bits are used as confidence, the other bits are reserved

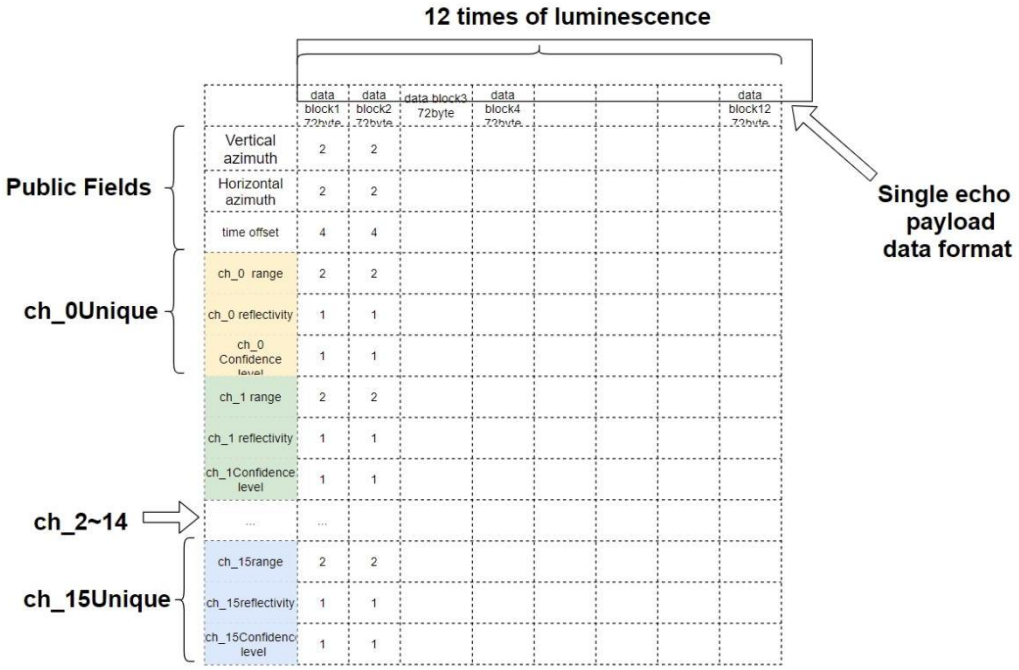
c) MDOP frame tail

Frame-tail contains 6 Bytes in total, see the table below for details:

Field	Offset (Bytes)	Number of bytes (Bytes)	Value	Description
Checksum	0	4	/	HEADER + PAYLOAD verification
End Flag	4	2	0x00 0xFF	End tag, fixed value

d) Packaging method

- Single Echo Mode
  There are 12 emissions for one UDP packet.



- Dual Echo Mode
  There are 6 emissions for one UDP packet.

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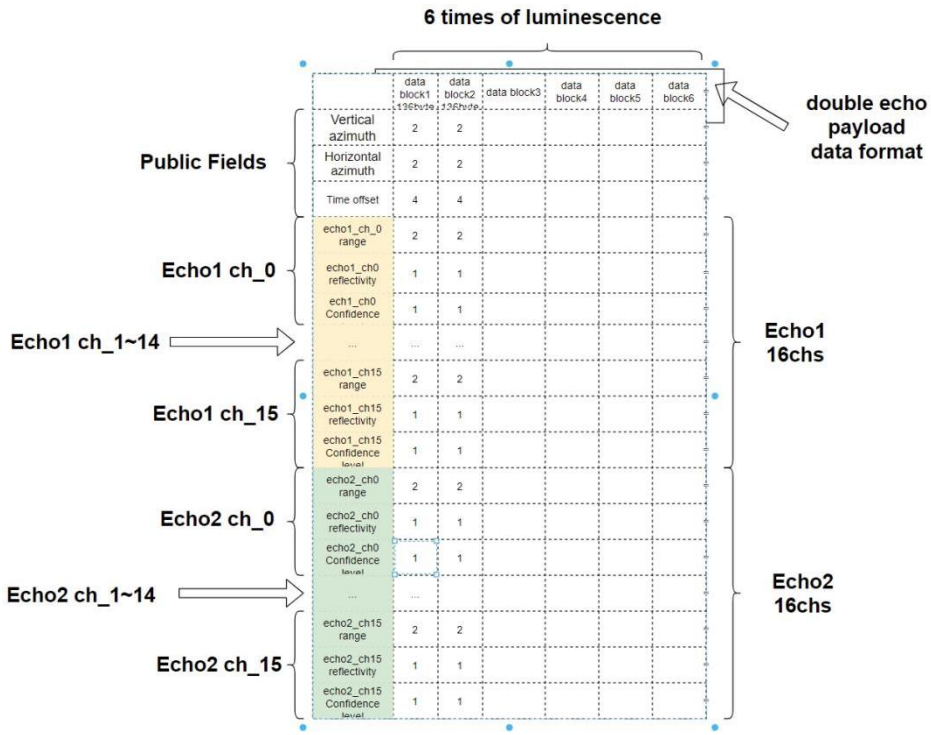

3.2.2 Device Command Protocol (DCSP)

Description:

- Device Command Protocol: DCSP stands for Device Command Set Protocol.
- Mainly responsible for transmitting different functional instructions (commands) to the LiDAR sensor and enabling it to execute the response protocol. The length of the whole frame is variable, the frame header is fixed to **10 Bytes**, the payload length is **variable**, and the frame tail is fixed to **6 Bytes**.
- The output data is of I/O type, and the LiDAR analyzes the command and responds.

The basic structure of the device command protocol is as follows:

Field	Header	Payload	Tail
Number of bytes (Bytes)	1 0	N (variable)	6
Description	Frame header	Load	End of frame
Remarks: • All Reserve bytes are padded with 0x00 • All multi-byte combination values are transmitted in little-endian mode (that is, the low bit is transmitted first, then the high bit). • The entire frame length cannot be more than 1467 Bytes			

a) DCSP header

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A total of 10 Bytes, mainly used to identify the data starting position, product version, DCSP protocol type, etc.; the detailed structure is shown in the following table:

Field	Offset [Bytes]	Length [Bytes]	Value	Description
SOF	0	2	"BW"	Start tag, fixed value
Product Identifier	2	1	0x01: AD2-S-X3	Product version
Protocol Identifier	3	1	0x02: DCSP request 0x03: DCSP response	DCSP protocol type
Protocol Version	4	2	0x0000	DCSP protocol version
Count	6	4	0x0000	Packet count value ● **DCSP request:** a. Each time a DCSP request is sent, the sequence is incremented by 1, and counting starts from 0 again when overflow occurs. It is an unsigned integer. b. The Count value of the retransmitted packet remains unchanged. ● **DCSP response:** a. Return the count value in the request package

b) DCSP payload

It is the command part in the protocol packet, with variable length. It is divided into two types: DCSP request payload and DCSP response payload.

❖ DCSP request payload

Mainly responsible for sending specific instructions to LiDAR sensor. The detailed structure is shown in the table below:

Field	Offset (Bytes)	Number of bytes (Bytes)	Description
Request command ID	0	1	Request opcode
Request command data length	1	2	Requested command length
Request command data	3	Request command data length	Requested command data

❖ DCSP response payload

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Mainly responsible for transmitting information that the device responds to instructions sent by the computer. There are two types of responses. See the table below for details:

Response payload—positive response			
Field	Offset (Bytes)	Bytes	Description
Response command ID	0	1	Response opcode: corresponds to the response request
Response command data length	1	2	Response Status length + Response data length
Response status	3	2	0x00: Will respond, no error
Response data	3	/	Response data: If the command has response data, return the response data

Response payload—negative response				
Field	Offset (Bytes)	Number of bytes (Bytes)	valu e	Description
Response command ID	0	1		Response opcode: corresponds to the response request
Response command data length	1	2	2	Response status length
Response Status	3	2		Non-0x00: negative response; its value indicates the error code. For detailed definition, see DCSP error summary

❖ DCSP command summary:

Serial number	Command ID	Command name	Whether to support LiDAR runtime execution	Command description
1	0x00	Get Device Information	yes	Get device information
2	0x02	START/STOP Sampling	yes	Start/stop sampling
3	0x07	Set IP and Port	no	Set IP and service port number
4	0x0A	Get Timestamp Format	yes	Get timestamp format
5	0x0B	Set Timestamp Format	yes	Set timestamp format
6	0x0C	Get LiDAR Mode	yes	Get LiDAR mode
7	0x0D	Set LiDAR Mode	yes	Set LiDAR mode
8	0x18	Get MDOP port	yes	Get MDOP port number
9	0x20	Download Firmware	no	Download firmware
10	0x73	Restart	no	Restart

▪ DCSP command definition:

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- Get Device Information:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x00	Get Device information request
Data length	1	2	0x0000	Get Device information request data length

- START/STOP Sampling:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x02	START/STOP sampling request
Data length	1	2	0x0001	START/STOP sampling request data length
Parameter	3	1	0x00: Stop 0x01: Start	

- Set IP and Port:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x07	Set IP and Port request
Data length	1	2	0x0018	Set IP and Port request data length
IP	3	4		
MDOP Port	7	4		
DSOP Port	11	4		
DCSP Port	15	4		
Mask	19	4		
Gateway	23	4		

- Get timestamp format:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x0a	Get timestamp request
Data length	1	2	0x0000	Get timestamp request data length

- Set timestamp format:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x0b	Set timestamp request
Data length	1	2	0x0001	Set timestamp request data

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				length
Timestamp format	3	1	0x00: No sync source 0x01: PTP (1588V2) 0x02: NTP 0x03: GPS+PPS 0x04: PPS 0x05: gPTP	

- Get LiDAR Mode:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x0C	Get LiDAR mode request
Data length	1	2	0x0000	Get LiDAR mode request data length

- Set LiDAR Mode:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x0D	Get LiDAR mode request
Data length	1	2	0x0001	Get LiDAR mode request data length
Mode	3	1	0x00: mode 0 0x01: mode 1	

- Get MDOP port:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x18	get MDOP port request ID
Data length	1	2	0x0000	get MDOP port request data length

- Download firmware:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x20	Download firmware request ID
Data length	1	2	1+4+4+Firmware data length	Download firmware request data length

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Transfer flag	3	1	Bit0-First package Bit1-last package Remarks: bit1: When bit0 is 01, it is the first package bit1: When bit0 is 10, it is the last package	Transfer mark
Sum bytes of firmware	4	4		The total length of the Bin file
Package count	8	4		Send download packet count, starting from 0
Firmware data	12	n	Bin file data	The length n cannot exceed the limit length of a single UDP packet. (Default 1024)
Remarks: 1. In cyclic packet sending, each request corresponds to a response, the transfer flag bit0 of the first request is 1, and the transfer flag bit1 of the last request is 1; 2. Firmware and FPGA files are temporarily downloaded uniformly through this command; 3. If the Host Computer GUI does not receive the response from the firmware within 500ms, the Host Computer GUI needs to resend the request, in which all data in the request will not be modified. A total of 3 attempts. If all three communication attempts fail, it will fail.				

- Restart:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Command ID	0	1	0x73	Restart request
Data length	1	2	0x0000	Restart request data length

c) DCSP frame tail: 6 Bytes in total

Field	Offset (Bytes)	Length (Bytes)	Value	Description
Checksum	0	4	/	HEADER + PAYLOAD verification
End flag	4	2	0x00 0xFF	End tag, fixed value

3.2.3 Device Status Protocol (DSOP)

Description:

- This protocol is used to transmit the status of the device.
- The length is 90 Bytes, the frame header is fixed at 52 Bytes, the payload is at a fixed length of 32 Bytes, and the frame tail is at a fixed length of 6 Bytes.

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- The output data type is I/O type, and the debugging computer analyzes it.

The basic structure of the device status protocol is as follows:

Field	Header	Payload	Tail
Length (Bytes)	52	32	6
Description	Frame header	Load	End of frame
Remarks: • All reserve bytes are padded with 0x00 • All multi-byte combination values are transmitted in little-endian mode (low byte first, high byte later)			

a) DSOP header

A total of 52 Bytes, mainly used to identify product version, DSOP protocol type, protocol version, LiDAR SN number, protocol port number and other information; the detailed structure is shown in the table below:

Field	Offset (Bytes)	Length (Bytes)	Value	Description
SOF	0	2	"BW"	Start mark, fixed value, 'B' is sent first, then 'W'
Product Identifier	2	1	0x01: AD2-S-X3	Product version
Protocol Identifier	3	1	0x01: DSOP	Protocol type
Protocol Version	4	2	0x0000	Protocol version
SN	6	32	/	Device SN number
DCSP_port	38	2	/	Protocol port number
Timestamp	40	8	/	Time-stamp
Count	48	4	/	The count value is incremented by 1 at a time, and counting starts again from 0 when overflow occurs.

b) DSOP payload

A total of 32 Bytes, which is the device status data part in the DSOP protocol package. The detailed structure is shown in the following table:

Field	Offset (Bytes)	Length (Bytes)	Description
DSOP_content_type	0	1	0: Universal heartbeat frame interval 1s
monitor_status_info	1	12	Monitor status information
sys_status_info	13	4	System status information
eth_status_info	17	1+n*port	Ethernet status information
DTC_info	17+1+n*port	/	DTC information
DID_info	20+X	max 369	Version information
DSOP_content_type	0	1	1: Functional safety frame

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			interval 100ms
functional_safety_info	1	14	Functional safety information

c) DSOP frame tail

There are 6 Bytes in total, see the table below for details:

Field	Offset (Bytes)	Length (Bytes)	Description	Field
Checksum	0	4	/	HEADER + PAYLOAD verification
End flag	4	2	0x00 0xFF	End tag, fixed value

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4 Sensor Maintenance

This section introduces the device storage, transportation, cleaning and other information of AD2-S-X3 LiDAR.

4.1 Device storage

- It is recommended to use the original packaging provided by Benewake for storage.
- Please store the sensor in an environment of -40℃ ~ +105℃, relative humidity ⩽ 60%, ensure the ventilation and no corrosive gases, and avoid exposure to direct sunlight.
- When storing, please avoid contact with corrosive substances, such as acids, alkalis, oils and other solutions, and keep away from all heat sources.
- If the storage time exceeds three months, please perform a working test on the sensor before use to ensure that the it can be used under normal conditions.
- Please regularly check the status of all components and packaging of the device.

4.2 Equipment transportation Device storage

- During transportation, loading and unloading, please handle it with care and avoid collisions and severe mechanical impacts to avoid damage or direction deviation of the optical components inside the sensor.
- Please follow the instructions on the packaging during transportation and loading, and pay attention to moisture.
- During transportation, do not place the device in an unstable place and avoid incorrect handling to prevent the sensor damage and personal injury.
- During transportation, please avoid contact with corrosive substances, such as acids, alkalis, oils and other solutions.

4.3 Equipment cleaning

- Before starting the device, please check whether the window glass is clean. If there is dirt (such as dust, fingerprints or oil stains, etc.), please clean it properly.
- Before routine cleaning, please unplug the device from the power supply, keep the device turned off, and use a soft cloth to gently wipe the window glass in the same direction. Avoid violent wiping, which may cause damage to the window glass.

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- If the equipment is operated in a harsh environment for a long time, the window glass should be cleaned regularly.
- Contamination of the window glass may affect the quality of point cloud data. In order to obtain the best performance of the sensor, please check and clean the device window regularly.
- For deep cleaning of internal optics, please contact support@benewake.com to get professional advice.

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5 Trouble Shooting

This section introduces the common problems and countermeasures of AD2-S-X3 LiDAR.

Table. 2: Frequently Asked Questions and Answers

Serial number	Question	Answers
1	Device cannot start	❖ Check whether the power supply voltage is normal ❖ Check whether the connector is connected properly ❖ Check whether the power supply current is normal and enough, 9~16V power supply, starting current needs to be > 3A ❖ Check whether addition and configuration of device in the software is done correctly ❖ Power it on again and test
2	Unable to connect to the network	❖ Check whether the cable end connector is tightly plugged in ❖ Check whether the computer network controller is normal, or change the computer and retest. ❖ Check whether the IP address is bound and whether the computer IP and LiDAR IP are in the same LAN segment ❖ Power on again and test
3	Point cloud display is abnormal or cannot be displayed	❖ Check if the computer firewall is turned off ❖ Use Wireshark packet capture tool to check whether the data packet is complete ❖ Check whether the window glass is blocked by external objects ❖ Check whether the software configuration is correct ❖ Power on again and test
4	A lot of noise appears in point clouds	❖ Check whether the window glass is contaminated ❖ Check whether the target object is a strong reflector ❖ Power on again and test
5	Abnormal view angle of point cloud	❖ Check whether the window glass is contaminated ❖ Check whether the window glass is blocked by external objects ❖ Check whether the software configuration is correct ❖ Power on again and test
6	Insufficient ranging capabilities of the sensor	❖ Check whether the window glass is contaminated ❖ Pay attention to weather visibility ❖ Check whether the window glass is blocked by external objects ❖ Check whether the software configuration is correct ❖ Power on again and test

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