C16

USER MANUAL

V3.5.2 2022.04

LeiShen Intelligent System Co., LTD http://www.lslidar.com/

Safety Instruction

Before using the product, please read and follow the instructions of this manual carefully, and refer to relevant national and international safety regulations.

ΔAttention

Please do not disassemble or modify the Lidar privately. If you need special instructions, please consult the technical support staff of LeiShen Intelligent.

ΔLaser Safety Level

The laser safety of this product meets the following standards:

● IEC 60825-1:2014

● 21 CFR 1040.10 and 1040.11 standards, except for the deviations (IEC 60825-1, third edition) stated in the Laser Notice No. 56 issued on May 8, 2019. Please do not look directly at the transmitting laser through magnifying devices (such as microscope, head-mounted magnifying glass, or other forms of magnifying glasses).

Eye Safety

The product design complies with Class 1 human eye safety standards. However, to maximize self-protection, please avoid looking directly at running products.

ΔSafety Warning

In any case, if the product is suspected to have malfunctioned or been damaged, please stop using it immediately to avoid injury or further product damage.

Housing

The product contains high-speed rotating parts, please do not operate unless the housing is fastened. Do not use a product with damaged housing in case of irreparable losses. To avoid product performance degradation, please do not touch the photomask with your hands.

Operation

This product is composed of metal and plastic, which contains precise circuit electronic components and optical devices. Improper operations such as high temperature, drop, puncture or squeeze may cause irreversible damage to the product.

Power Supply

Please use the connecting cable and matching connectors provided by LeiShen Intelligent to supply power. Using cables or adapters that are damaged or do not meet the power supply requirements, or supply power in a humid environment may cause abnormal operation, fire, personal injury, product damage, or other property loss.

Light Interference

Some precise optical equipment may be interfered with by the laser emitted by this product, please pay attention when using it.

Vibration

Please avoid product damage caused by strong vibration. If the product's mechanical shock and vibration performance parameters are needed, please contact LeiShen Intelligent for technical support.

Radio Frequency Interference

The design, manufacture and test of this product comply with relevant regulations on radiofrequency energy radiation, but the radiation from this product may still cause other electronic equipment to malfunction.

Deflagration and Other Air Conditions

Do not use the product in any area with potentially explosive air, such as areas where the air contains high concentrations of flammable chemicals, vapours or particles (like fine grains, dust or metal powder). Do not expose the product to the environment of high-concentration industrial chemicals, including near evaporating liquefied gas (like helium), so as not to impair or damage the product function.

Maintenance

Please do not disassemble the Lidar without permission. Disassembly of the product may cause its waterproof performance to fail or personal injury.

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1. Product Profile

1.1 Overview

The C16 lidar realizes 360° three-dimensional high-speed scanning though 16 dense laser beams, with a detection distance of up to 200 m, a measurement accuracy of ±3 cm, and a vertical angular resolution of 2°. It is widely used in unmanned driving, automotive ADAS, smart transportation, service robot, logistics, surveying and mapping, security, industry, ports and other fields.

1.2 Working Principle

The C16 mechanical lidar adopts the Time of Flight method. The lidar starts timing (t1) when the laser pulses are sent out. And when the laser encounters the target object and the light returns to the sensor unit, the receiving end stops timing (t2).

Distance = Speed of Light*(t2 – t1)/2

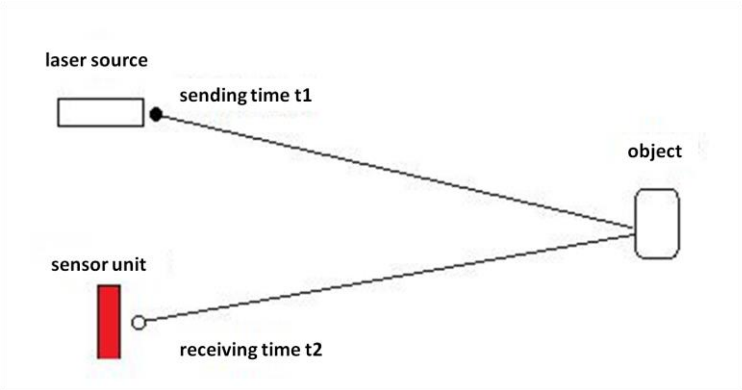

Figure 1.1 C16 Lidar Working Principle

1.3 Specification

Table 1.1 Specifications (2° Linear Distribution)

Model	C16-xxxB /C16-xxxD
Detection Method	Pulse
Wavelength	905 nm
Laser Class	Class 1 (eye-safe)
Channels	16
Detection Range	70 ~200 m

Range Accuracy		±3 cm
Data Point Generated (Single Echo Mode)		320,000 pts/sec
Data Point Generated (Dual Echo Mode)		640,000 pts/sec
FOV	Vertical	-15~+15° (No 0° laser)
	Horizontal	360°
Angular Resolution	Vertical	2° (Linear Distribution)
	Horizontal	5 Hz: 0.09° / 10 Hz: 0.18° / 20 Hz: 0.36°
Scanning Rate		5 Hz / 10 Hz / 20 Hz (Configurable)
Communication Interface		Ethernet / PPS
Operating Voltage		+9 V～+36 VDC
Operating Temperature		-20℃～+60℃ (B) / -40℃～+60℃ (D)
Storage Temperature		-40℃～+85℃
Shock Test		500 m/sec², lasting for 11 ms
Vibration Test		5 Hz～2000 Hz, 3G rms
IP Grade		IP67
Dimensions		Φ102 mm*81 mm
Weight		800 g (Standard Edition) / 650 g (Lightweight Edition)

1.4 Dimensions

There are 2 location holes and 4 M4 screw mounting holes at the bottom of the lidar. The lidar's horizontal angle of 0° is at the position of the data line interface (or opposite to the interface, please consult sales for more information). The C16 Lidar is equipped with 16 pairs of laser transmitter and receiver modules. It rotates in a clockwise direction, and its motor is driven at a rotation speed of 5 Hz/10 Hz/20 Hz to cover a 360° scan range.

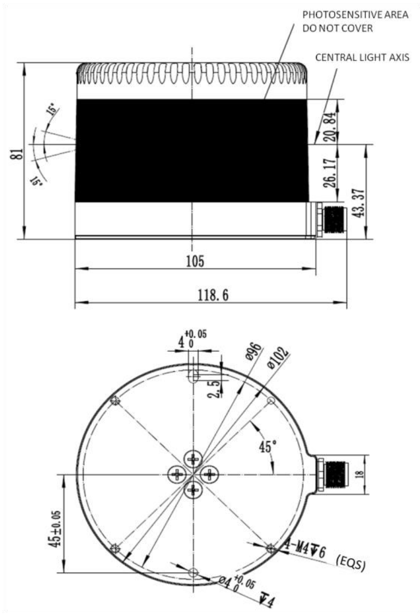

Figure 1.2 Dimensional Drawing

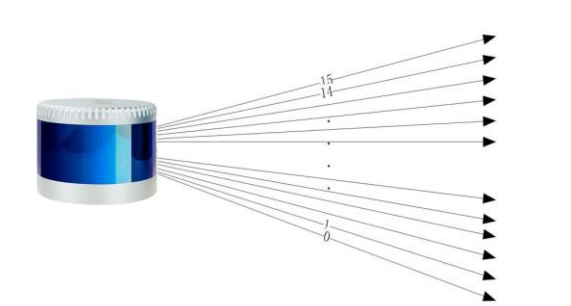

Figure 1.3 Wiring Harness

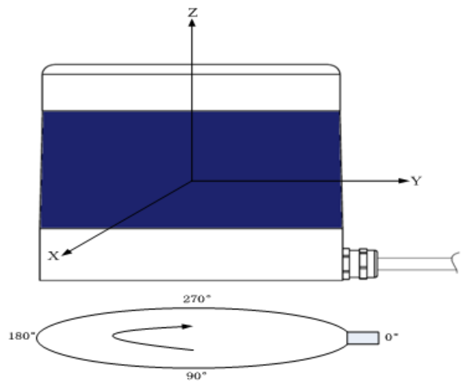

Figure 1.4 Coordinates & Scanning Direction

2. Electrical Interface

2.1 Power Supply

The power input range is 9V～36VDC. If other DC power supply is adopted, the recommended output voltage of the power supply is 12VDC, 19VDC or 24VDC. Please note that DC 9V and 36V are short-term power supply in extreme environment, which cannot be used as working voltage. When the voltage output fluctuates, the lidar may not be able to work normally.

The maximum output current should be ≥2A (the lidar requires a large instantaneous current when starting, and a small starting current may cause its failure to start normally). The output ripple noise should be <120 mVp-p and output voltage accuracy <5%.

The higher the power supply voltage and the stronger the discharge capacity, the more severe the impact on the lidar (such as powered by direct vehicle power supply without adapters and interface boxes). Therefore, it is necessary to use high-power TVS transient suppression diodes to protect the lidar to avoid damage.

The line length of the lidar power supply is 5~10 m, and the voltage needs to be over 19V. If the line length is more than 10 m, then it is recommended to use a 220VAC adapter nearby for power supply (DC long-distance power supply is not recommended).

2.2 Electrical Interface

2.2.1 Electrical Connection

The C16 LiDAR is connected through an interface box by default. There are two wiring methods. The default option is to use the standard cable of the LeiShen Intelligent, which is 1.8 meters long. The other is to use the aviation plug cable which is divided into two parts: the part connecting the lidar is 1.2 meters long, and the part connecting the interface box is 0.3 meters long.

Figure 2.1 Interface Box and Lidar Connection (left: standard cable; right: aviation plug cable)

2.2.2 Interface Box

On the interface box, there are a Φ2.1 mm DC socket, an indicator light, a RJ45 network port and a 6-pin GPS port, as shown in Figure 2.3. The function of the interface box is to facilitate the power adapter's and Ethernet cable's direct connection to the lidar. If the interface box is not needed, the user can move the 8-pin terminal wires out of the box and connect them to the power supply, Ethernet interface and GPS device interface separately. To realize this, the user only needs to disassemble the interface box housing, disconnect the solder joints of the wires, and take out the terminal wires from the interface box.

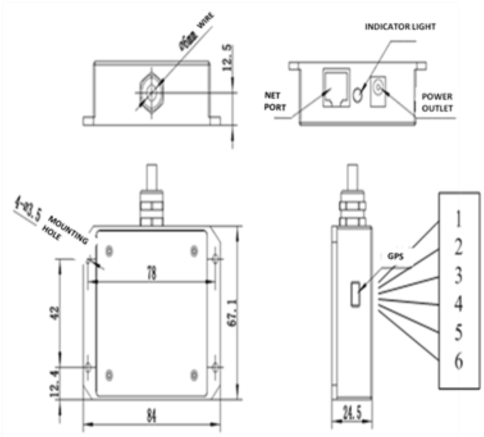

Figure 2.2 Interface Box Dimensional Drawing

Table 2.1 GPS Interface Definition

PIN	Definition
1	NC
2	GND
3	GPS_REC
4	GND
5	+5V
6	GPS_PPS

2.2.3 Wiring Definition

The cable end (8-PIN shielded wires, as shown in Figure 2.1 below) on the side of the C16 lidar bottom base is a standard female socket of LeiShen Intelligent. While the cable end (8-PIN shielded wires, as shown in Figure 2.2 below) of the interface box is a standard male plug.

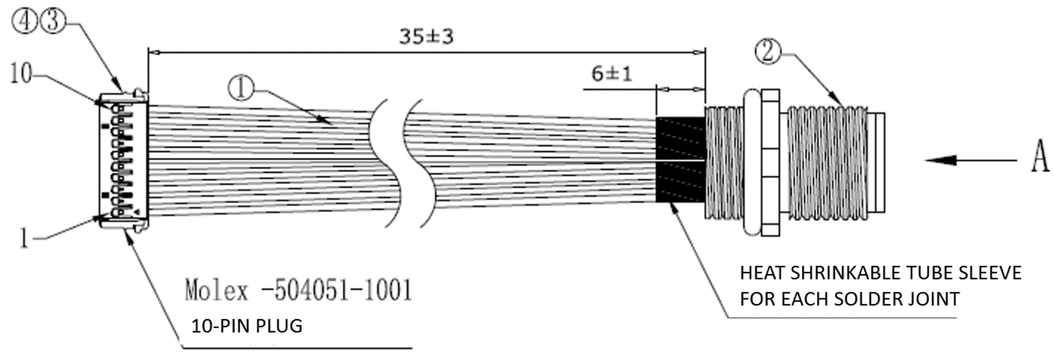

Figure 2.3 Lidar Base Cable

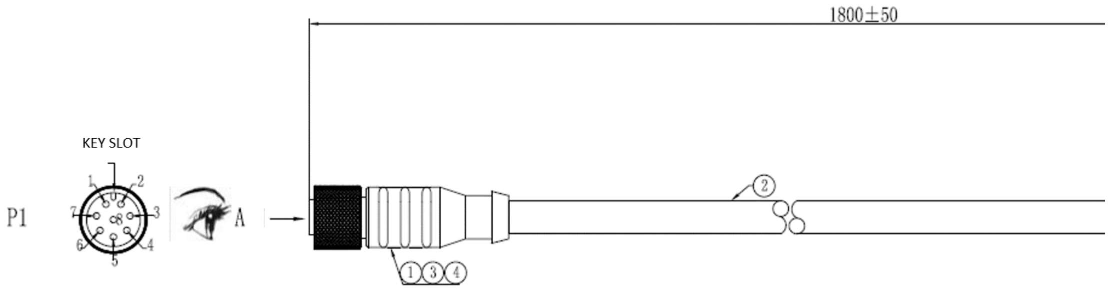

Figure 2.4 Side cable the Interface Box

Table 2.2 The Specifications and Definitions of the 8-PIN Cable

S/N	Wire Color & Size	Definition	Description
1	Red（20AWG）	VCC	Power+
2	Light Blue（24AWG）	TD_N	Ethernet TX-
3	Blue（24AWG）	TD_P	Ethernet TX+
4	Light Orange（24AWG）	RD_N	Ethernet RX-
5	Orange（24AWG）	RD_P	Ethernet RX+
6	Yellow（20AWG）	GPS_PPS	GPS Inputting PPS Signal
7	White（20AWG）	GPS_Rec	GPS Receive
8	Black（20AWG）	GND	Power-（GND）

3. Get ready

3.1 LiDAR Connection

To get ready for the lidar operation, please connect the lidar to the computer as shown in figure 3.1.

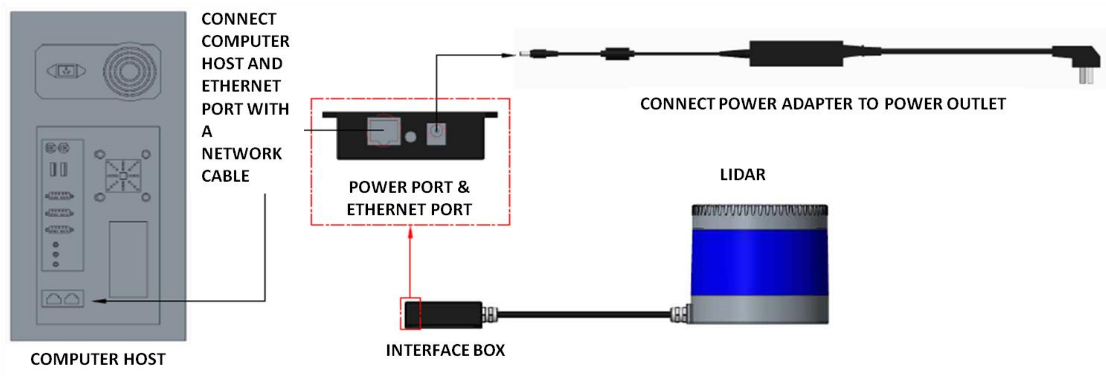

Figure 3.1 Connecting Lidar and Computer

3.2 Software Preparation

The LeiShen C16 Lidar can be operated under both Windows operating system and Linux operating system. Software needed is as follows:

Wireshark: to capture the ARP (Address Resolution Protocol) packets.

Note: Wireshark is a third-party software, users need to download it by themselves. LeiShen Intelligent bears no responsibility for any copyright and commercial disputes caused by users' use of the software.

To view the point cloud data generated by the lidar, users can either use the **LeiShen Lidar Viewer** or the **ROS Drive Program.**

LeiShen Lidar Viewer (optional): a host computer software to view point cloud image under Windows operating system, which is also referred to as point cloud display software.

- Software Acquisition

This Lidar viewer has been pre-stored in the USB flash drive provided along with the lidar. It can also be obtained from the sales or technical support personnel. No installation is required for the viewer.

- Operating Environment

This software can only run under the Windows x64 operating system at present.

The computer configuration requirements for installing the software are: CPU: Intel(R) Core(TM) i5 or higher, graphics card: NVIDIA GeForce GTX750 or higher achieves the best effect, otherwise the display of the point cloud may be affected.

- Supplemental Software

To use the LeiShen Lidar Viewer, the installation of the WinPcap third-party library is necessary. This software has also been pre-stored in the USB flash drive provided with the lidar.

To install the WinPcap software, please follow the following steps:

Step 1. Insert the USB drive into a computer port and open it.

Step 2. Find the WinPcap installation file and double-click it to initiate the installation.

Step 3. Click “next” to enter the installation path selection interface. (please do not use Chinese path)

Step 4. Click “next” to enter the installation interface.

Step 5. Click the “install” button, and wait for the installation to be completed.

ROS Drive Program (optional): to view the point cloud data under Linux operating system. This program has been pre-stored in the USB flash drive provided with the lidar. It can also be obtained from the sales or technical support personnel. No installation is required.

4. Usage Guide

This part is to guide users and developers to use the C16 Lidar and supporting lidar point cloud display software presented by the LeiShen Intelligent System Co. Ltd.

4.1 Operation Under Windows OS

4.1.1 Lidar Configuration

The point cloud display software coming with the lidar can be used to analyze data package and device package information, and display 3D point cloud data. Lidar parameters can be reset through the visual interface of the point cloud display software. The default IP address and port number of the lidar network are as follows:

Table 4.1 Default LiDAR Network Configuration

	IP Address	UDP Device Package Port Number	UDP Data Package Port Number
Lidar	192.168.1.200	2368 (Fixed)	2369 (Fixed)
Computer	192.168.1.102	2369	2368

Note:

1) The lidar IP (local IP) and the computer IP (destination IP) cannot be set to the same, otherwise the lidar will not work normally.
2) In the multicast mode, no two destination ports should be set to the same port number.

When connecting to the lidar, if the computer IP and the lidar IP are in different network segments, users need to set the gateway; if they are in the same network segment, users only need to set different IPs, for example: 192.168.1.x, and the subnet mask is 255.255.255.0. If users need to find the Ethernet configuration information of the lidar, please connect the lidar to the computer and use “Wireshark” to capture the ARP packet of the device for analysis. For the feature identification of the ARP packet, see the figure below.

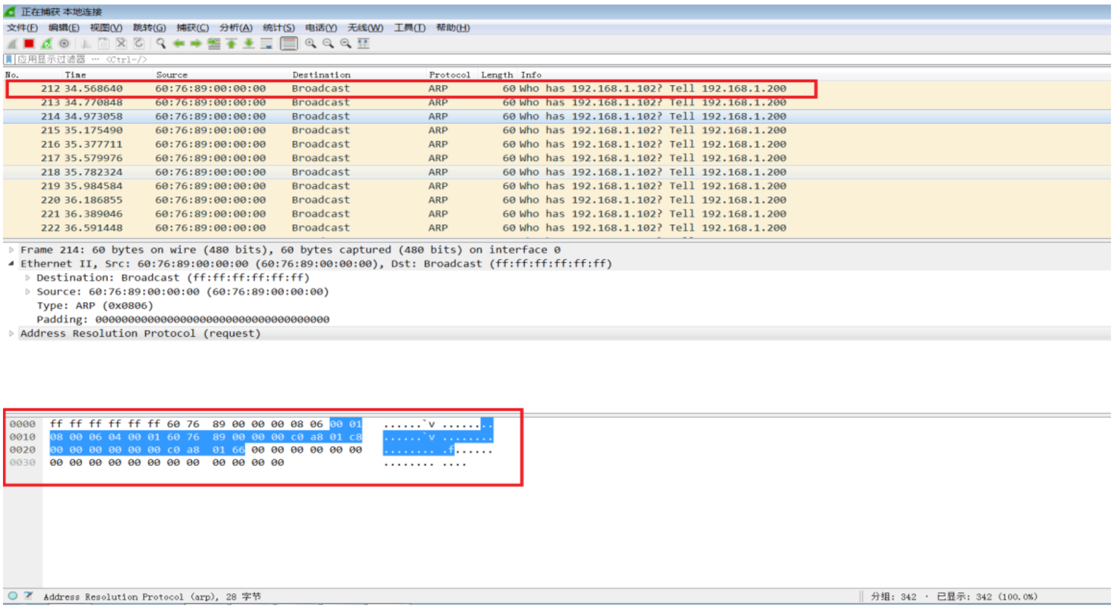

Figure 4.1 Wireshark Captures ARP Packet

4.1.2 LeiShen Lidar Viewer Interface

The software interface includes menu area, tool bar area, 3D window area, data table area, etc.

Note: To view the software version, click "Help->About" in the tool bar.

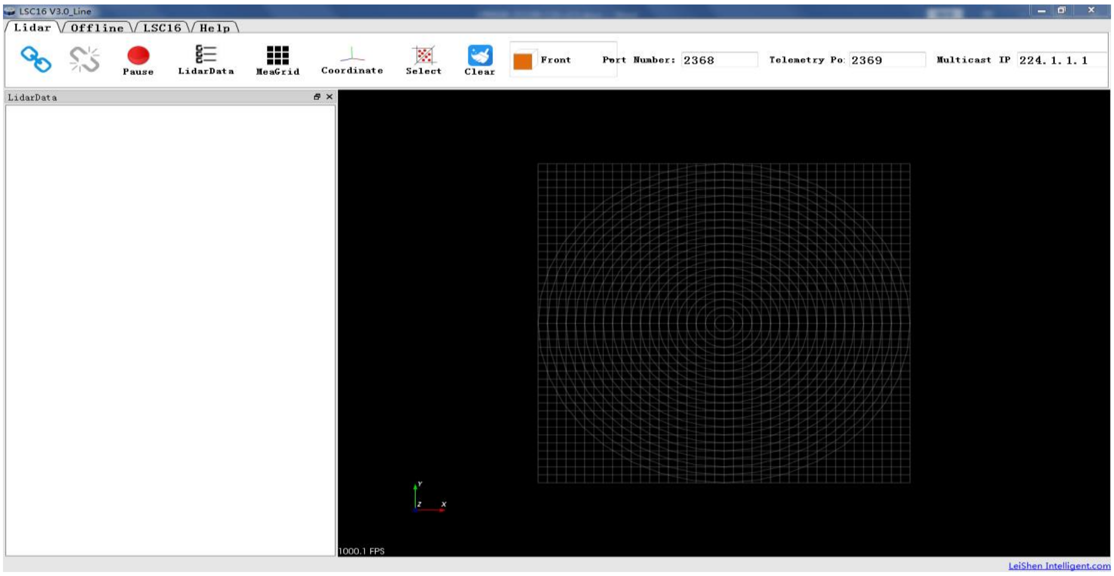

Figure 4.2 LeiShen Lidar Viewer Interface

In the point cloud display area (right side), with 20 circles and 40*40 grids, the radius of each two adjacent circles differs by 10 m. The difference between every two grids (horizontal or longitudinal) is 10 m. And the radius of the outermost circle is 200 m.

The grids and circles make it easy to view the position of the point cloud. The direction of the coordinate axis in the 3D display interface is consistent with the direction of the X-Y axis in the point cloud reference system.

Point cloud display interface supports the following operations:

1) Zoom in/out the display interface with the mouse wheel; hold the right mouse button and drag it up/down to zoom in/out.

2) Hold the left mouse button and drag it to adjust the angle of view;

3) Hold the mouse wheel and drag it to pan the display interface; or hold the shift key on the keyboard and the left mouse button to pan the interface.

Menu button function introduction

- Lidar Menu

Button	Description
	Connect/disconnect lidar

Clear	Clear screen	
Coordinate	Show/hide coordinate	
Front	Three-view option: set the observation angle from top, front, and left.	
Pause	Pause point cloud image and data generating	
MeaGrid	Show/hide measurement grid	

- Offline Menu

Button	Description	
Open	Open offline data	
Record	Record and save data, valid only when lidar receives data in real time	
	Skip to the beginning	
	When paused, view the previous frame; When playing, rewind (click multiple times to select 2x, 3x, 1/2x, 1/4x and 1x speed)	2x 3x 1/2x 1/4x
	Click to start playing after the point cloud file is loaded When playing, click to pause	
	When paused, view the next frame; When playing, fast forward (click multiple times to select 2x, 3x, 1/2x, 1/4x and 1x speed)	2x 3x 1/2x 1/4x
	Skip to the end	
198	Drag the progress bar or enter the frame number to skip to the specified position	

- Parameter Menu

Button	Description	
Parameter	Open lidar parameter form	The upper part of the form shows the lidar configuration. The parameters include local IP,

		destination IP, subnet mask, gateway, local port, destination port, and motor speed setting (5Hz/10Hz/20Hz can be selected under combo box), whether to obtain the local time, Mac address information, and device packet sending interval. The lower part shows the real-time status information. According to the DIFOP status packet sent out regularly by the lidar, the current status information is displayed, including GPS position information, satellite time information, motor speed, current lidar IP, and current lidar port number.
Channel	Select laser channel	Vertical Angle column represents the vertical angle of the corresponding channel data and Channel column represents the data sequence number corresponding to the channel.
SaveData	Save the data in .csv format	
DualEcho	Set the mode of echo	Dual echo, strongest echo, second echo
Intensity	Set the display mode of the point cloud	Intensity, laser ID, azimuth angle, etc.

4.1.3 Operation Procedure

Step 1. Set the data port number (default 2368), device package port number (default 2369), and multicast IP.

Data Port: 2368 Telemetry Port: 2369

Multicast IP: 224.1.1.1

Step 2. Click to receive the lidar data in real time.

Step 3. The data table contains (PointID, Points_m_XYZ, adjustedtime, Azimuth, Distance_m, Intensity, Channel, timestamp).

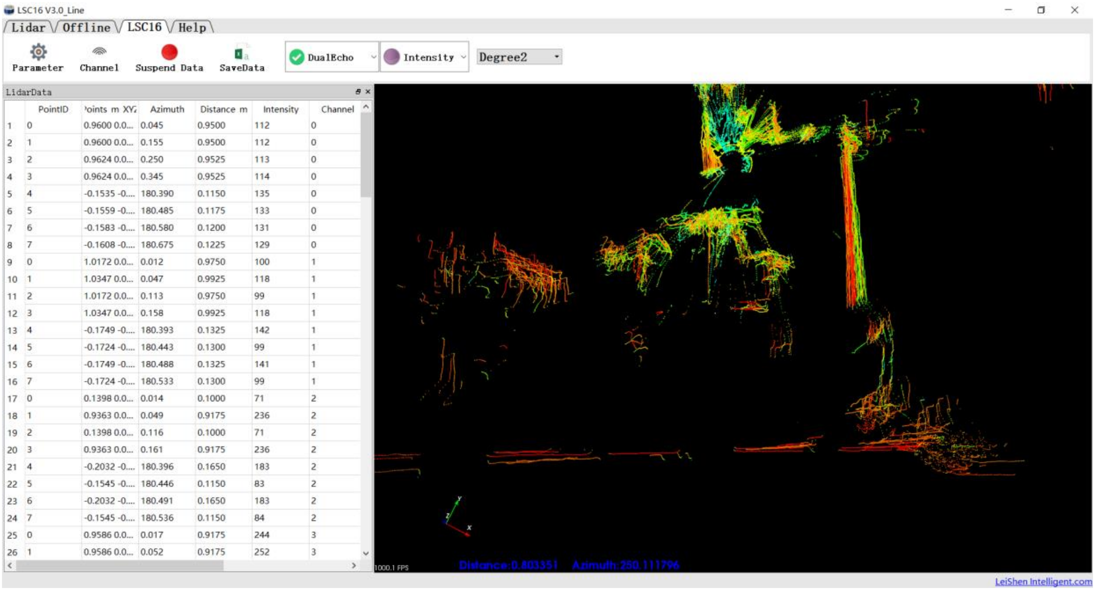

Figure 4.3 Real-Time Data Receiving Interface

4.1.4 Point Cloud Data Parsing

If users need to parse lidar data, please follow the steps below:

Step 1. Parse the data package to obtain the relative horizontal angle, ranging information, intensity data and microsecond timestamp information of each laser;

Step 2. Read the device package to obtain information such as the horizontal correction angle value, UTC time (GPS or NTP time service) and the current configuration of the device;

Step 3. Obtain the vertical angle of each line according to the laser beam distribution;

Step 4. According to the distance measurement value, vertical angle and the calculated horizontal angle of the point cloud data, the XYZ coordinate values are obtained;

Step 5. If necessary, calculate the precise time of the point cloud data through UTC time, microsecond timestamp, light-emitting time of each laser, as well as single and dual echo modes;

Step 6. Reconfigure information such as Ethernet, PPS synchronization horizontal angle, motor speed and other information as needed, and pack the configuration package protocol.

4.1.5 Parameter Config Example of Lidar Network Communication Mode

Unicast

The lidar IP address and the destination IP address are in the same network segment.

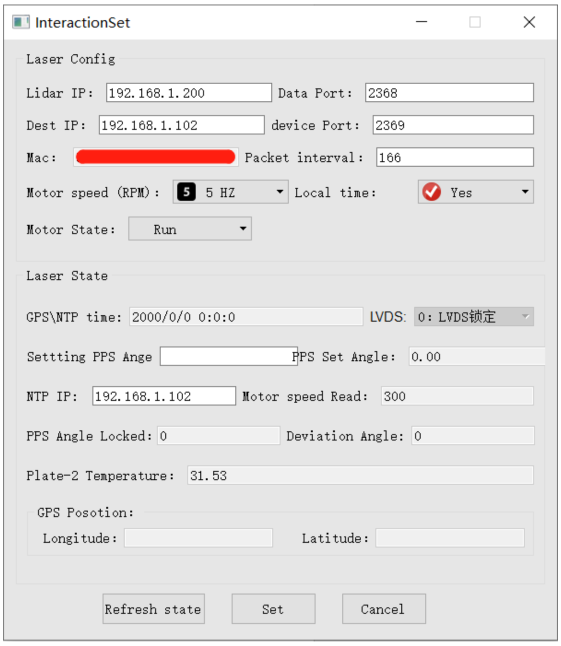

Figure 4.4 Unicast Configuration (1)

When the lidar IP address and the destination IP address are in different network segments, for example, the destination IP address is 192.168.10.102, and the lidar IP is 192.168.1.200, then a switch is needed to connect the lidar and the computer.

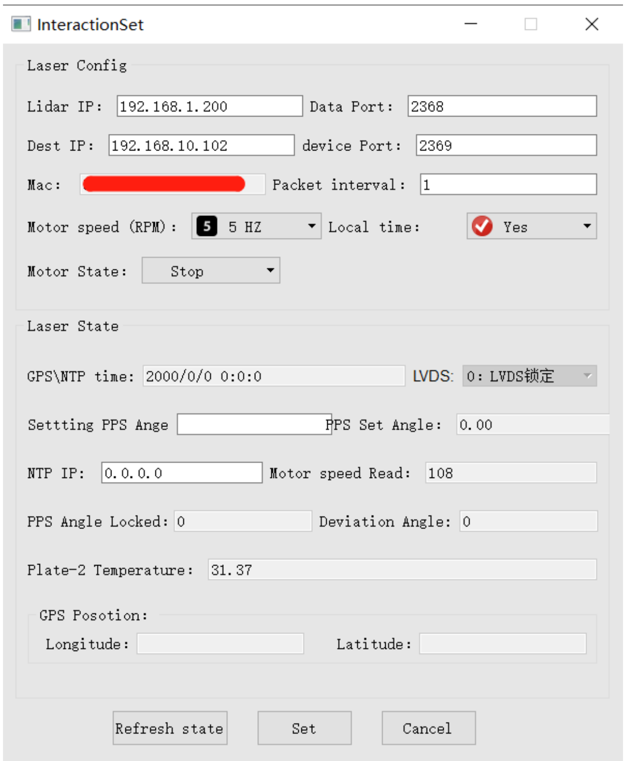

Figure 4.5 Unicast Configuration (2)

Multicast

The destination IP is the address of the multicast group.

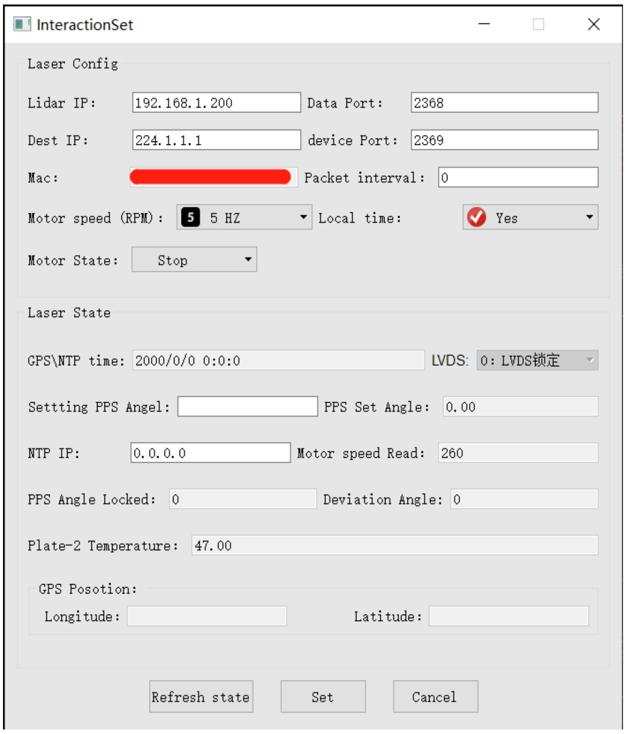

Figure 4.6 Multicast Configuration

Broadcast

Under the broadcast mode, the destination IP address is the broadcast address, and the lidar IP address and the destination IP address are in the same network segment.

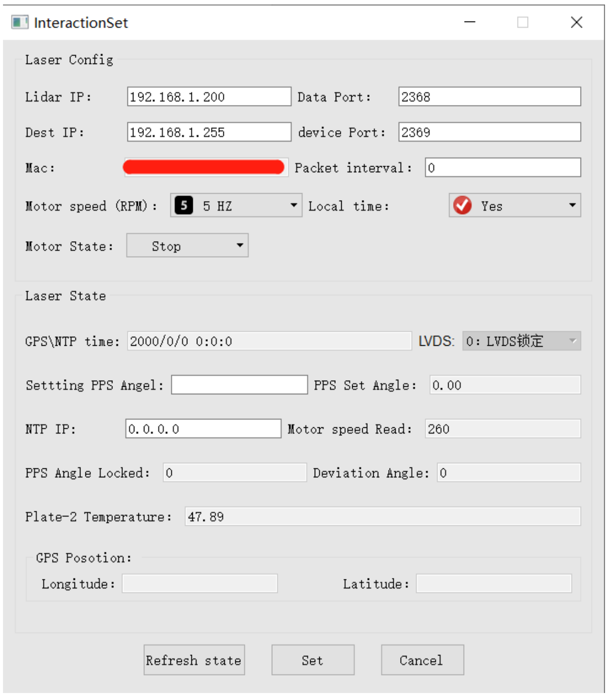

Figure 4.7 Broadcast Configuration (1)

When the destination IP address is the broadcast address, but the lidar IP address and the destination IP address are not in the same network segment, then a switch is needed to connect the lidar and the computer.

Figure 4.8 Broadcast Configuration (2)

4.1.6 Note

Notice about the lidar setting and usage:

1) It is not possible to use LeiShen C16 lidar display software to receive data in two processes (open twice at the same time) in the same computer. The port occupancy of the PC is generally exclusive, so the other software that uses the same process or the same port number cannot work normally after a process is bound to a specified port number. When LeiShen C16 lidar display software detects that the port is occupied, it will prompt that the communication network port configuration has failed, and automatically close the software. The user needs to close the software process that occupied the port, and reopen the LeiShen C16 lidar display software to use it normally.

2) At the same time, since Qt is adopted in the low-level software development, the Chinese path cannot be recognized. Therefore, please do not use the Chinese path when naming files and path folders.

3) Since the port number of the LeiShen C16 lidar can be modified through user configuration, and the lidar sends data to the host computer through the preset destination IP and port. Therefore, when the local laptop or desktop computer and other devices are receiving data, their IP address should be the same as the destination IP, and the port bound to the local host computer program needs to

be the same as the destination port number, as shown in the figure below (these are the data packet parameters captured and analyzed by Wireshark software). The data in the red boxes indicate the destination IP and port number of the lidar.

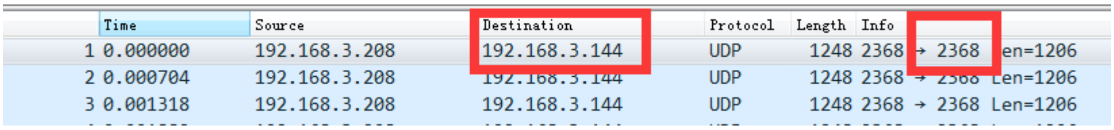

Figure 4.9 Data Packet Parameters Captured by Wireshark Software

Please set the host computer IP according to the following steps:

Step 1. In the Control Panel -> Network and Internet -> Network Sharing Center, click the “local connection” button.

Step 2. Click “Properties” in the pop-up status box, and click “TCP/IPv4 protocol” in the pop-up properties box, as shown in the figure below.

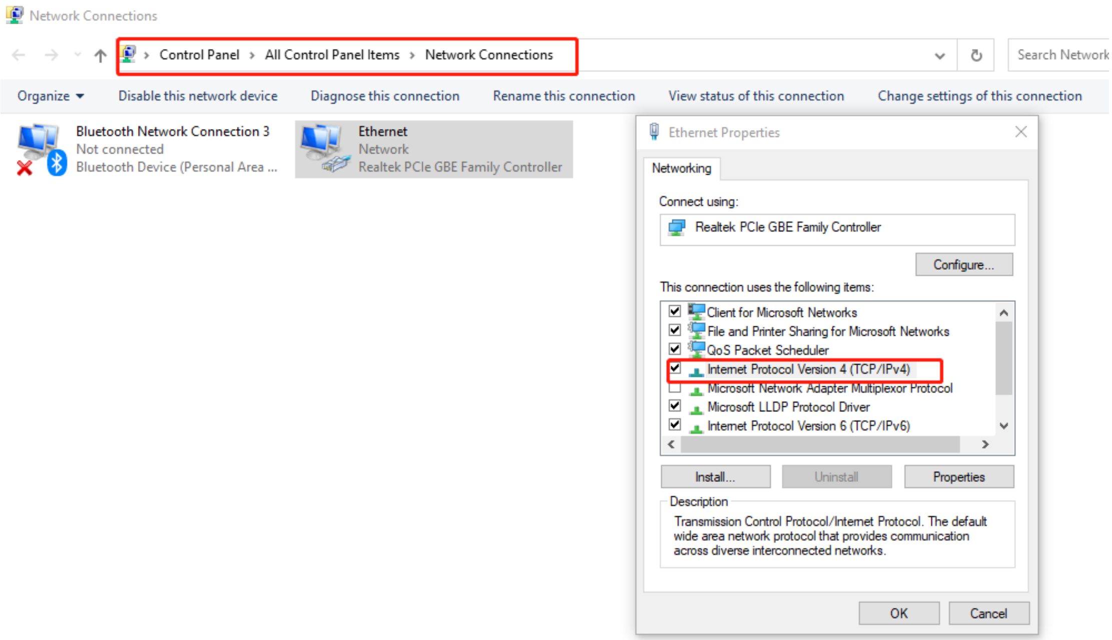

Figure 4.10 Network Connections

Step 3. In the TCP/IPv4 property settings, set the IP address to the lidar's destination IP (The default destination IP of the lidar is 192.168.1.102 and the default port number is 2368), and the subnet mask is set to 255.255.255.0.

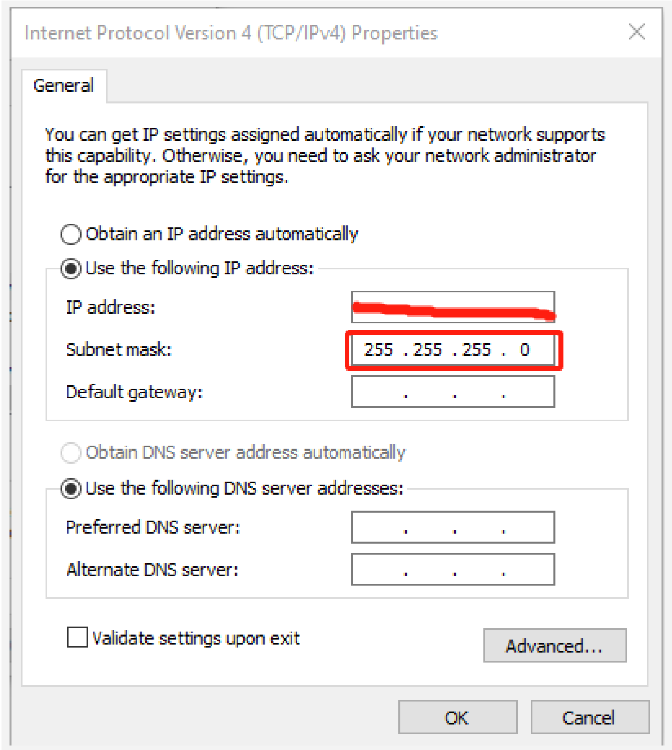

Figure 4.11 IP Address and Subnet Mask Setting

4) Since the LeiShen lidar display software needs to obtain a large number of data packets through the network in a short time, it may be considered as a malicious program by the network firewall and be prohibited. Therefore, there may be situations in which the data packet has been sent to the computer by the Wireshark software, but the point cloud display software cannot display it.

To address this problem, in Control Panel -> System and Security -> Windows Firewall Settings, click to allow this program to pass through Windows Firewall, setting steps are as shown in the figures below:

Step 1. In Control Panel -> System and Security -> Windows Defender Firewall, click “Allow an app or feature through the Windows Defender Firewall”.

Step 2. Browse to find the software installation path, select it and click OK.

Step 3. Tick the part marked in the red box according to the nature of the user's network, and click OK to see the data.

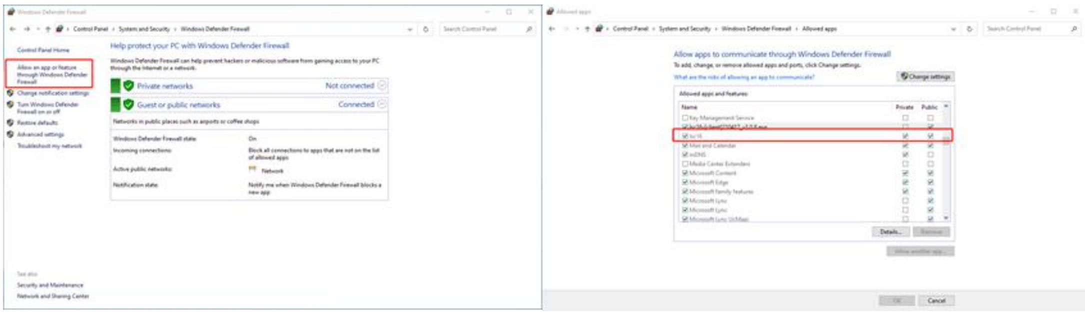

Figure 4.12 Windows Defender Firewall Setting

Computer graphics settings

When installing the LeiShen lidar display software on a desktop or laptop with dual graphics cards, the default global settings of the computer operating system is to use the global settings (automatic selection: integrated graphics), which affects the display efficiency of the software. In order to ensure the use and display efficiency of the software, users need to manually set the computer graphics.

The condition of dual graphics cards can be checked in the computer configuration, and the condition of the display adapter can be seen in My Computer->Properties->Device Manager.

Take a laptop with Intel(R)HD Graphics 530 integrated graphics and NVIDIA GeForce GTX 960 discrete graphics as an example. The setting steps to manually switch the applicable graphics card of the software to high-performance discrete graphics card are as follows:

Step 1. Right-click on a blank space on the desktop to pop up a right-click menu and select “NVIDIA Control Panel”.

Step 2. Select the “Manage 3D Settings” in the NVIDIA Control Panel interface.

Step 3. Click the “Program Settings” button in the Manage 3D Settings interface.

Step 4. Click the “Add” button on the Manage 3D Settings interface.

Step 5. Click the “Browse” button in the pop-up interface.

Step 6. Find the application file (.exe file) of the software according to its installation path in the pop-up browsing interface.

Step 7. Click “OK” to automatically return to the NVIDIA control panel, select the high-performance NVIDIA processor in the combo box of the preferred graphics processor for this program in Option -2., and click “Apply” in the lower right corner. After the computer application is set, close the NVIDIA Control Panel to complete the setting.

4.2 ROS Driver Operation Under Linux OS

4.2.1 Hardware Connection and Test

Step 1. Connect the lidar to the internet and power supply

Step 2. Set the computer wired IP according to the destination IP of the lidar, (whether the computer wired IP is set successfully can be checked by the ifconfig command, as shown in the figure, the destination IP is 192.168.1.102)

```
ls@ls-Inspiron-15-3511:~$ ifconfig
enxf8e43b292f8c: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 192.168.1.102  netmask 255.255.255.0  broadcast 192.168.1.255
        inet6 fe80::898a:1bfd:a729:2f4e  prefixlen 64  scopeid 0x20<link>
        ether f8:e4:3b:29:2f:8c  txqueuelen 1000  (以太网)
        RX packets 254127  bytes 313581906 (313.5 MB)
        RX errors 254118  dropped 3  overruns 0  frame 254118
        TX packets 76  bytes 9406 (9.4 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

Figure 4.13 ifconfig Command Feedback

Note: The default destination IP of the lidar is 192.168.1.102, and the computer must be configured according to the actual lidar destination IP. After setting the IP for the first time, please restart the lidar.

Step 3. After the lidar is powered on and restarted, check the wired connection icon of the computer to see whether it is connected properly.

Step 4. Open the terminal: ping the lidar IP, and test whether the hardware is connected normally. If the ping is successful, then the data is received, otherwise check the hardware connection.

Step 5. Use "sudo tcpdump -n -i eth0" (here eth0 is the name of the wired network device, see the device name of ifconfig wired connection display for details) to view the data packets sent by the lidar (as shown in the figure, there are 1206-byte data packets sent by the lidar to the destination, which means that the lidar data is sent normally).

```
leishen@robot:~$ sudo tcpdump -n -i eth0
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on eth0, link-type EN10MB (Ethernet), capture size 262144 bytes
19:49:08.973111 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.973717 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.974308 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.974913 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.975517 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.976107 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
19:49:08.976714 IP 192.168.1.200.2368 > 192.168.1.102.2368: UDP, length 1206
```

Figure 4.14 sudo tcpdump -n -i eth0 Command Feedback

4.2.2 Software Operation Example

Step1. Establish a workspace and build a compilation environment

mkdir -p ~/leishen_ws/src

cd ~/leishen_ws

Note: The workspace can be named arbitrarily. For example, "leishen_ws" can be changed to any name.

Step 2. Download the lidar driver

The driver and dependency package can also be obtained directly from our website or customer service. Copy the obtained driver file to the newly created workspace "src", and decompress it.

Step 3. Compile and package

cd ~/leishen_ws

catkin_make

Step 4. Run the program

source ~/leishen_ws /devel/setup.bash

roslaunch lslidar_c16_decoder lslidar_c16.launch --screen

Note 1): If the lidar destination port and motor speed are modified, please open "lslidar_c16.launch" to modify the configuration accordingly. The default port is 2368, and the speed is 10Hz, that is to say, the point_num is 2000 points.

Note 2): If timeout appears, it means that the driver has no data reception. Please check the hardware connection.

Reopen a terminal again and execute the following command:

rosrun rviz rviz

Note 3): If steps 1, 2, and 3 have been completed, next time after the "Displays Window" is reopened, start directly from step 4.

Step 5. Display the data detected by the lidar

In the "Displays Window" that pops up, modify the value of "Fixed Frame" to "laser_link". Click the "Add" button at the same time, and click "PointCloud2" under "By topic" to add a multi-line point cloud node.

5. Communication Protocol

Lidar data output and configuration use 100M Ethernet UDP/IP communication protocol. There are 3 UDP packet protocols, and the packet length is 1248 bytes (42 bytes Ethernet header and 1206 bytes payload). The lidar supports unicast, broadcast and multicast communications.

The communication protocols of the lidar are:

Main data Stream Output Protocol (MSOP): outputting the distance, angle, intensity and other information measured by the lidar;

Device Information Output Protocol (DIFOP): outputting the current status of lidar and accessory equipment and various configuration information;

User Configuration Write Protocol (UCWP): setting the configuration parameters of the lidar.

Table 5.1 UDP Packet Protocol

Protocol Name	Abbreviation	Function	Length	Transmission Interval
Main data Stream Output Protocol	MSOP	Outputting measured data and timestamp	1248bytes	1.2 ms (single echo) 0.6 ms (dual echo)
Device Information Output Protocol	DIFOP	Outputting parameter configuration and status information		0.33 s
User Configuration Write Protocol	UCWP	Inputting user configured device parameters		not fixed

5.1 MSOP Protocol

The data package outputs measured data such as the angle value, distance value, intensity value, and timestamp of the point cloud. The data of the package adopts Little-Endian mode.

The data package includes a 42-byte Ethernet header and a 1206-byte payload, with a total length of 1248 bytes. The payload consists of 1200 bytes of point cloud data (12 data blocks of 100 bytes) and 6 bytes of additional information (4 bytes of Timestamp and 2 bytes of Factory).

5.1.1 Format

The C16 lidar supports single and dual echo modes. Single echo mode measures the most recent echo value, and dual echo mode measures the most recent echo and the second recent echo value.

In the single echo mode, one echo data is measured after a single-point laser emission. A point cloud data package contains 12 data blocks, and each data block contains 2 sets of 16-channel point cloud data measured in the packing order. Each data block returns only one azimuth angle, and each azimuth angle outputs 2 sets of data. See the picture below:

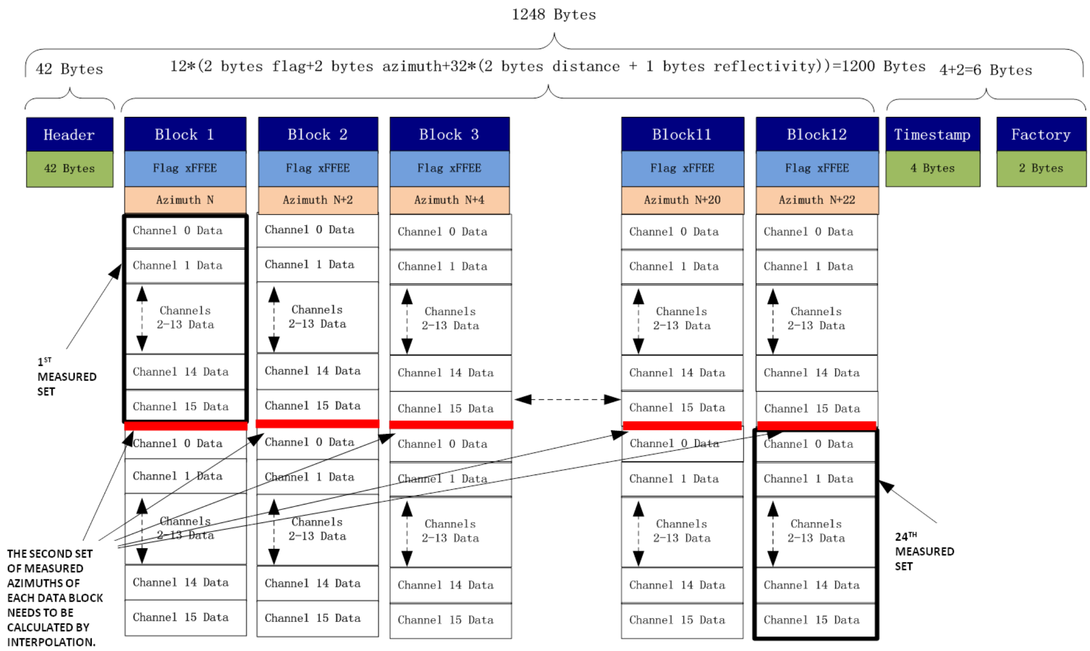

Figure 5.1 Data Format of the Single Echo Mode

When dual echo mode is adopted, two echo data is measured after a single-point laser emission. The data package contains 6 parity data block pairs, and every 2 data blocks contains 2 sets of two echo values of 16 channels measured in the packing order. Block (1, 2) is the two echo data of the first 2 sets of 16 point cloud data. The odd block is the first echo data, and the even block is the second echo data; the Block (3, 4) is the two echo data of the next 2 sets of 16 point cloud data, ..., and so on. Only one azimuth angle is returned for each parity data block pair. See the picture below:

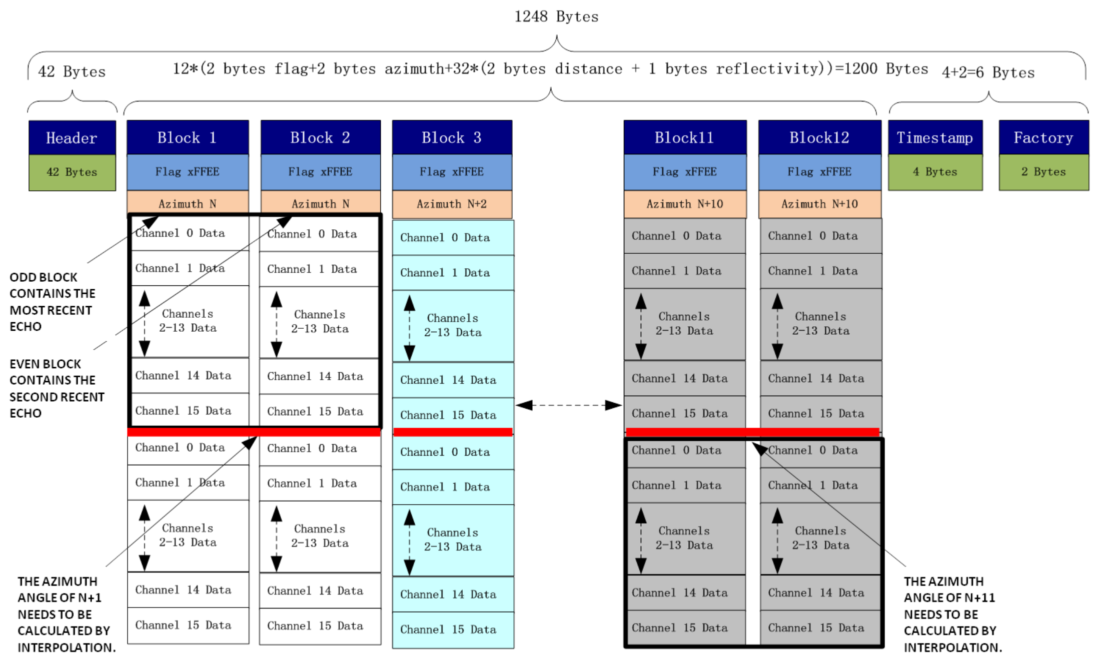

Figure 5.2 Data Format of the Dual Echo Mode

5.1.2 Data Package Parameter Description

Ethernet Header

The Ethernet header has a total of 42 bytes, as shown in the table below.

Ethernet Header: 42 bytes				
Name	S/N	Information	Offset	Length（byte）
Ethernet II MAC	0	Destination	0	6
	1	Source	6	6
Ethernet Packet Type	2	Type	12	2
Internet Protocol	3	Version, Header Length, Differentiated Services, Field, Total Length, Identification, Flags, Fragment Offset, Time to Live, Protocol, Header, Checksum, Source IP Address, Destination IP Address	14	20
UDP Port Number	4	LiDAR Port (0x0941, represent 2369)	34	2
	5	Computer Port (0x0940, represent 2368)	36	2
UDP Length & Sum	6	Length (0x04BE, represent 1214 bytes)	38	2
	7	Sum Check	40	2

Check				

Data Block

The measured data has a total of 1200 bytes, which is composed of 12 data blocks, and each data block is 100 bytes in length.

A data block includes:

● 2 bytes 0xffee fixed value flag bit;

● 2 bytes Azimuth's relative horizontal angle information;

● 2 sets of 16-channel point cloud data (each channel 3 bytes). Each set of channel data (UDP packet encapsulation sequence) corresponds to a 16-channel laser measurement data of the lidar at a certain launch time.

Note: The packing order of channel data increases in order. This order may be inconsistent with the vertical angle distribution order of the channel and the laser emission measurement time order of the channel, but there is a fixed one-to-one correspondence.

Azimuth

The horizontal angle value—Azimuth represents the angle of the first channel 0 of the data block, and its unit is 0.01 degrees. The resolution of the horizontal angle value corresponds to 0.09°, 0.18° and 0.36° according to the motor speed 5Hz, 10Hz and 20Hz.

Channel Data

Channel data is an unsigned integer, the 2 high bytes are distance, and the 1 low byte is intensity, as shown in the following table.

Channel N Data（3 bytes）		
Byte3	Byte2	Byte1
Distance	Distance	Intensity

The unit of distance is 0.25cm. The echo intensity represents the energy reflection characteristics of the measured object, and the intensity value represents the intensity level of 0-255 different reflectors.

Additional Information

The additional information is 6 bytes in length, including 4 bytes of microsecond Timestamp and 2 bytes of Factory.

Additional Information: 6 bytes

Name		Length (byte)	Function
Timestamp		4	Timestamp (μs)
Factory	Echo information	1	0x37 represents the strongest echo, 0x38 the last echo，0x39 the dual echo
	Vendor information	1	0x10 represents C16 LiDAR，0x20 represents C32 LiDAR

When the NTP service synchronization timing is turned on, the timestamp is synchronized with the time of the NTP server. The range of the timestamp is 0-999999 (μs);

If the NTP synchronization time service is invalid:

1) When there is a GPS device inputting PPS signal to the lidar, the timestamp is generated with the PPS time as the cycle time, and the range of the timestamp is 0-999999 (μs);

2) When there is an external synchronization device inputting PPS signal, the timestamp is generated with the external synchronization PPS time as the cycle time, and the range of the timestamp is 0-999999 (μs);

3) When there is no synchronization device inputting PPS signal, the lidar generates timestamps with a period of 1 hour. The range of the timestamp is 0-3599_999_999 (μs).

5.2 DIFOP Protocol

The device package outputs read-only parameters and status information such as version number, Ethernet configuration, motor speed and operating status, and fault diagnosis. The data of the device package adopts Big-Endian mode.

The device package includes a 42-byte Ethernet header and a 1206-byte payload, with a length of 1248 bytes. The payload is composed of 8-byte frame header, 1196-byte data and 2-byte frame tail.

Figure 5.2 Data Format of the Device Package

Ethernet Header: 42 bytes				
Name	**S/N**	**Information**	**Offset**	**Length（byte）**
Ethernet II MAC	0	Destination	0	6
	1	Source	6	6
Ethernet Packet Type	2	Type	12	2

Internet Protocol	3	Version, Header Length, Differentiated Services, Field, Total Length, Identification, Flags, Fragment Offset, Time to Live, Protocol, Header, Checksum, Source IP Address, Destination IP Address	14	20
UDP Port Number	4	LiDAR Port (0x0940, represent 2368)	34	2
	5	Computer Port (0x0941, represent 2369)	36	2
UDP Length & Sum Check	6	Length (0x04BE, represent 1214 bytes)	38	2
	7	Sum Check	40	2
Payload: 1206 bytes				
Name	**S/N**	**Information**	**Offset**	**Length（byte）**
Header	0	Device Package Identification Header	0	8
Data	1	Motor Speed	8	2
	2	Ethernet (IP, Port, MAC, NTP）	10	22
	3	Ethernet (Gateway, Subnet Mask)	32	8
	4	LiDAR Rotation / Stationary	40	2
	5	Device Flow Packet Interval	42	8
	6	PPS Alignment Angle Value	48	2
	7	PPS Angle Deviation Value	50	2
	8	UTC Time	52	6
	9	Latitude and Longitude	58	22
	10	Temperature of No. 2 Plate	80	2
	11	Vertical Angle Measurement (1-16 Channels)	245	32
	12	Lidar Serial Number	1164	20
	13	Version	1196	2
Tail	14	Frame Tail	1204	2

Header is the device packet identification header, which is fixed as 0xA5, 0xFF, 0x00, 0x5A, 0x11,0x11,0x55, 0x55, and the first 4 bytes can be used as the packet inspection sequence. Tail is fixed at 0x0F, 0xF0.

5.3 UCWP Protocol

The UCWP configures the lidar's Ethernet, PPS alignment angle, motor speed and other parameters, and the data of the configuration package adopts the Big-Endian mode.

The configuration packet includes a 42-byte Ethernet header and a 1206-byte payload, with a length of 1248 bytes. The payload is composed of 8-byte Header, 1238-byte Data, and 2-byte Tail.

Note: It is recommended that users configure the lidar through the Windows point cloud display software, and users are forbidden to package and configure the lidar parameters by themselves; except for the Ethernet configuration, gateway, and subnet mask that require a restart of the lidar to take effect, other configurations take effect immediately.

Figure 5.3 Data Format of the Configuration Package

Ethernet Header: 42 bytes				
Name	**S/N**	**Information**	**Offset**	**Length（byte）**
Ethernet II MAC	0	Destination	0	6
	1	Source	6	6
Ethernet Packet Type	2	Type	12	2
Internet Protocol	3	Version, Header Length, Differentiated Services, Field, Total Length, Identification, Flags, Fragment Offset, Time to Live, Protocol, Header, Checksum, Source IP Address, Destination IP Address	14	20
UDP Port Number	4	LiDAR Port (0x0941, represent 2369)	34	2
	5	Computer Port (0x0940, represent 2368)	36	2
UDP Length & Sum Check	6	Length (0x04BE, represent 1214 bytes)	38	2
	7	Sum Check	40	2
Payload: 1206 bytes				
Name	**S/N**	**Information**	**Offset**	**Length（byte）**
Header	0	Configuration Package Identification Header	0	8
Data	1	Motor Speed	8	2
	2	Ethernet (IP, Port, MAC, NTP）	10	22
	3	Ethernet (Gateway, Subnet Mask)	32	8
	4	LiDAR Rotation / Stationary	40	2
	5	Configuration Flow Packet Interval	42	2
	6	PPS Alignment Angle Value	48	2
	7	UTC Time	52	6
Tail	8	Frame Tail	1204	2

Header is the configuration packet identification header, which is fixed as 0xAA, 0x00, 0xFF, 0x11,0x22, 0x22, 0xAA, 0xAA, and the first 4 bytes are used as the packet inspection sequence. The Tail of the frame is fixed at 0x0F, 0xF0.

5.3.1 Configuration Parameters and Status Description

Here below are the configuration parameters and status description of speific lidar information.

Motor Speed

Motor Speed（2 bytes）		
S/N	Byte1	Byte2
Function	Speed: 5Hz/10Hz/20Hz	

The motor rotates clockwise. Three speeds can be set: when it is set to 0x04B0, the speed is 1200rpm; when it is set to 0x0258, the speed is 600rpm; when it is set to 0x012C, the speed is 300rpm. Other setting data is not supported.

Ethernet Configuration

The length of the source IP address “IP_SRC” is 4 bytes and the length of the destination IP address “IP_DEST” is 4 bytes. Each lidar has a fixed MAC address “MAC_ADDR”, which cannot be configured by users. Port1 is the UDP data port number and port2 is the UDP device port number. NTP server address is 4 bytes in length. The internal time of the lidar can be synchronized from the server address through the NTP protocol.

Ethernet Configuration（22 bytes）								
S/N	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7	Byte8
Function	IP_SRC				IP_DEST			
S/N	Byte9	Byte10	Byte11	Byte12	Byte13	Byte14	Byte15	Byte16
Function	MAC_ADDR (Read Only)						Data Port: Port1	
S/N	Byte17	Byte18	Byte19	Byte20	Byte21	Byte22		
Function	Device Port: Port2		NTP server address					

PPS Alignment Horizontal Angle

When the lidar obtains the PPS signal input from the external device, it controls the lidar to scan to a specific horizontal angle at the moment. The configuration package sets the PPS alignment angle value, the unit of which is 0.01 degrees. For example, if the alignment angle is 90 degrees, the setting value should be 9000, and the hexadecimal number is 0x2328, corresponding to byte2 = 23h, byte1 = 28h.

PPS Alignment Angle Value（2 bytes）		
S/N	Byte1	Byte2
Function	Configuration PPS alignment angle	

The device package outputs the PPS synchronization time, and the difference between the actual scanning horizontal angle of the lidar and the set PPS alignment angle value. The unit of the alignment angle error is 0.01 degrees. “Valid is 0” indicates that the second pulse signal is valid. Angle_err[14:0] is the alignment angle error value, which is a signed integer with a range of -18000~18000, that is, between -180 degrees and 180 degrees.

Note: The default value of this parameter is set to be 0, which is defined that the PPS angle alignment function is not enabled by default. If the user needs the PPS to temporarily align 0 degrees, this parameter can be set to a small amount greater than 0, such as 0.01 or 1.

Alignment Angle Error (2 bytes Read Only)			
S/N	Byte1		Byte2
Function	valid	angle_err[14:0]	

UTC Time

When the lidar detects that the NTP server is turned on, UTC time synchronizes with the NTP server time; when NTP is turned off, the lidar receives GPS signals, parses the $GPRMC information, and UTC time synchronizes with GPS; when there is no NTP and GPS timing, UTC time is all 0s. The UTC (GMT Greenwich) time output by the device package is accurate to 1s. The GPS time data format is shown in the table below.

UTC Time（6 bytes Read Only）						
S/N	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6
Function	Year	Month	Day	hour	min	sec
	0~255 corresponding to the year 2000~2255	1~12 month	1~31 day	0~23 hour	0~59 min	0~59 sec

Lidar Rotation & Stationary

Lidar Rotation & Stationary（2 bytes）		
S/N	Byte1	Byte2
Function	0: Rotation；1: Stationary	

x0000 indicates that the lidar is rotating, 0x0001 indicates that the lidar is stationary, and the default value of the lidar is rotating scan.

Device Flow Packet Interval

Device Flow Packet Interval（2 bytes）		
S/N	Byte1	Byte2
Function	0: same as data packet interval; other values: one packet per second；	

The configuration 0x0000 means that the device packet and the data packet are sent at intervals, and other parameters mean 1 packet per second. The default value is 0x0001.

Latitude and Longitude

Latitude and longitude bytes（22 bytes Read Only）								
S/N	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7	Byte8
Function	Reserved	Latitude						
S/N	Byte9	Byte10	Byte11	Byte12	Byte13	Byte14	Byte15	Byte16
Function			Longitude					
S/N	Byte17	Byte18	Byte19	Byte20	Byte21	Byte22		
Function					N/S	W/E		

The latitude and longitude are output in the form of ASCII code.

Gateway Address

Gateway Address（4 bytes）				
S/N	Byte1	Byte2	Byte3	Byte4
Function	Gateway Address			

Subnet Mask

Subnet Mask（4 bytes）				
S/N	Byte1	Byte2	Byte3	Byte4
Function	Subnet Mask			

5.3.2 Configuration Package Example

If parameters like motor speed, IP address, lidar device port number, NTP server address, PPS alignment angle value, lidar rotation/stationary, etc. need to be reset, according to the definition of the configuration package, the 1206-byte payload is set as follows:

Table 5.4 Configuration Package Example

Info	**Content**	**Config**	**Length（byte）**
Header	-	0xAA,0x00,0xFF,0x11,0x22,0x22,0xAA,0xAA	8
Motor Speed	1200 rpm	0x04,0xB0	2
Lidar IP (IP_SRC)	192.168.1.105	0xC0,0xA8,0x01,0x69	4
Computer IP	192.168.1.22	0xC0,0xA8,0x01,0xE1	4

(IP_DEST)	5		
device (MAC_ADDR)	XXXX (Read Only)	0xxxxx	6
Data Port (port1)	XXXX	0xxxxx	2
Device Port (port2）	8899	0x22,0xC3	2
NTP Server Address	192.168.1.106	0xC0,0xA8,0x01,0x6A	4
Gateway	192.168.1.1	0xC0,0xA8,0x01,0x01	4
Subnet Mask	255.255.255.0	0xFF,0xFF,0xFF,0x00	4
Lidar Rotation/Stationary	Rotation	0x00,0x00	2
Device Flow Packet Interval	3 Packet	0x00,0x00	2
PPS Alignment Angle Value	1.28°	0x00,0x80	2
Tail	Fixed Value	0x0F,0xF0	2

Note: When encapsulating the configuration package, the entire package data must be written completely.

6. Time Synchronization

There are two ways to synchronize the lidar and external equipment: GPS synchronization and external PPS synchronization. If there is no external synchronization input, the lidar internally generates timing information. The absolute accurate time of the point cloud data is obtained by adding the 4-byte timestamp (accurate to microseconds) of the data packet and the 6-byte UTC time (accurate to seconds) of the device packet.

6.1 GPS Synchronization

When GPS synchronization is employed, the lidar will start timing in microseconds after receiving the PPS second pulse, and the time value will be output as the timestamp of the data packet. The lidar extracts UTC information from the $GPRMC of the GPS as the UTC time (accurate to the second) output of the device package.

There are two types of C16 lidar GPS_REC interface level protocols, namely TTL level standard and RS232 level standard; the GPS_REC interface specification on the power box is SH1.0-6P female socket. The two protocols differ in two aspects, respectively:

TTL level pin definition:

Pin GPS_REC receives the standard serial port data of the TTL level output from GPS module;

Pin GPS_PPS receives the positive TTL synchronous pulse signal output by the GPS module;

RS232 pin definition:

Pin GPS_REC receives the standard serial data of the R232 level output from the GPS module;

Pin GPS_PPS receives the positive synchronization pulse signal output by the GPS module, and the level is required to be 3.0V~15.0V.

If the GPS used outputs according to the RS232 serial port protocol, and the lidar receives data according to the TTL protocol, then a RS232 to TTL conversion module is needed.

The GPS equipment is time-synchronized to mark and calculate the precise emission and data measurement time of each laser. The precise time of the lidar point cloud can be matched with the pitch, roll, yaw, latitude, longitude and height of the GPS/inertial measurement system.

The default serial configuration baud rate of the GPS data output received by the lidar is 9600, 8N1. The PPS high pulse width is required to be more than 1ms.

The standard format of the GPRMC information is as follows:

$GPRMC, <1>, <2>, <3>, <4>, <5>, <6>, <7>, <8>, <9>, <10>, <11>, <12> *hh

Table 6.1 The Standard Format of GPRMC Information

S/N	Name	Description/Format
1	UTC Time	hhmmss (hour/minute/second)
2	Positioning State	A=Effective Positioning，V=Invalid Positioning
3	Latitude	ddmm.mmmm (degree/minute)
4	Latitude Hemisphere	N (Northern Hemisphere) or S (Southern Hemisphere)
5	Longitude	dddmm.mmmm (degree/minute)
6	Longitude Hemisphere	E (East Longitude) or W (West Longitude)
7	Ground Speed	000.0~999.9 knot

8	Ground Direction	000.0~359.9 degree, take true north as the reference datum
9	UTC Date	ddmmyy (day/month/year)
10	Magnetic Declination	000.0~180.0 degree
11	Direction of Magnetic Declination	E (East) or W (West)
12	Mode Indication	Only NMEA0183 version 3.00 outputs，A= autonomic positioning, D= difference, E=estimation, N=invalid data

The C16 Lidar is compatible with GPS interfaces of multiple data formats. The GPRMC data format only needs to meet the following two requirements: the data after the first comma separator is hour, minute and second information; the data after the ninth comma separator is date information. The following two formats can be used normally:

1) $GPRMC,072242,A,3027.3680,N,11423.6975,E,000.0,316.7,160617,004.1,W*67;

2) $GPRMC,065829.00,A,3121.86377,N,12114.68162,E,0.027,,160617,,,A*74.

6.2 External Synchronization

In external synchronization, the lidar receives the PPS signal input by other external devices and times it in microseconds, and the timing value is output as the timestamp of the data packet. At this time, there is no UTC time reference. If UTC time is required, it must be written in the configuration package, otherwise the UTC time output information of the device package is invalid.

The PPS level of the external synchronization signal is 3.3~5V, and the lidar receives the rising edge trigger, and the PPS high pulse width is required to be more than 1ms.

6.3 Lidar Internal Timing

When there is no GPS and other equipment to synchronize, the lidar uses 1 hour (360*10^6 μs) as the cycle, with microsecond as the timing unit, and the timing value is output as the timestamp of the data packet. At this time, there is no UTC time reference. If UTC time is required, it must be written in the configuration package, otherwise the UTC time output information of the device package is invalid.

7. Angle and Coordinate Calculation

7.1 Vertical Angle

Each channel of the C16 lidar corresponds to a fixed vertical angle, see the table below.

Table 7.1 C16 Vertical Angle (2°linear distribution)

UDP Packet Encapsulation Sequence (Channel)	Vertical Angle
Channel 0 Data	-15°
Channel 1 Data	1°
Channel 2 Data	-13°
Channel 3 Data	3°
Channel 4 Data	-11°
Channel 5 Data	5°
Channel 6 Data	-9°
Channel 7 Data	7°
Channel 8 Data	-7°
Channel 9 Data	9°
Channel 10 Data	-5°
Channel 11 Data	11°
Channel 12 Data	-3°
Channel 13 Data	13°
Channel 14 Data	-1°
Channel 15 Data	15°

By querying the above table, the vertical angle of the 16-channel data can be obtained.

Note: The vertical angle corresponding to the increasing channel number of the lidar does not increase sequentially from bottom to top. This is because the channel packing order of the data packet is consistent with the sequence of the light-emitting time of each channel, and the light-emitting is not sequentially from bottom to top. See the description of C16 luminous time for details.

7.2 Horizontal Angle

The horizontal angle value of each channel of the data packet needs to be calculated according to the light-emitting time of the 16 channels.

7.2.1 Horizontal Angle Calculation of Single Echo Mode

In a single-echo data packet, each data block has only one horizontal angle value, which represents the horizontal angle value corresponding to channel 0 of the earliest transmission measurement of this data block. The angles corresponding to the other two groups of 16 channels need to be interpolated. Because the lidar rotates at a constant speed, the light-emitting time interval of each channel of the data block is the same, so after interpolating the two adjacent angle values (Azimuth N and Azimuth (N+2)), and with the light-emitting time of each channel, the horizontal angle value corresponding to the remaining 31 laser shots of the block can be calculated.

The data block structure of the C16 single echo packet is as follows:

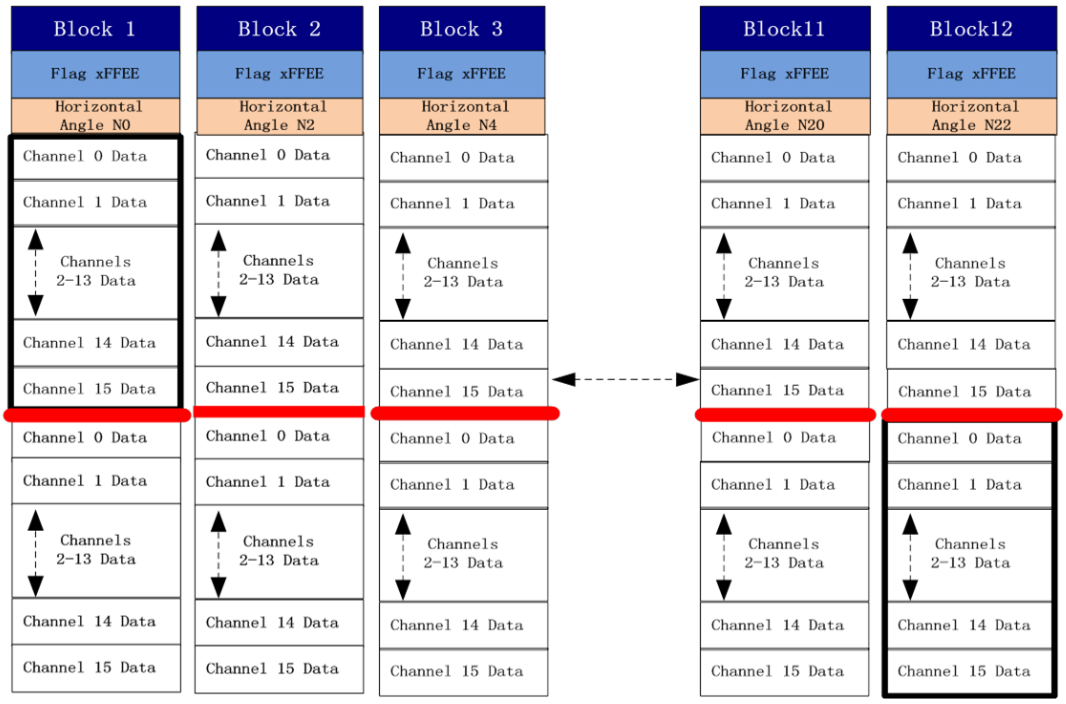

Figure 7.1 Single Echo Data Block Structure

Take the second set of Channel 15 data of Block 3 as an example:

1) The light-emitting moment angle of Channel 0 of the first set of Block3 is N4 degrees;

2) The angle of deflection between the light-emitting moment of the second set of Channel 0 of Block 3 and the light-emitting moment of the first set of Channel 0 is (N4-N2)/2 degrees. Therefore, the angle of the second set of channel 0's light-emitting moment is (N4+((N4-N2)/2)) degrees;

3) The time difference between the lighting time (T0+(15*T)) of the second set of Channel 15 of Block 3 and the lighting time T0 of the second set of Channel 0 is (15*T), the angle of deflection is (((N4-N2)/2)/16)*15 degrees. Therefore, the horizontal angle of the second set of Channel 15 light = the second set of

Channel 0's light-emitting moment angle + deflection angle = (N4+(N4-N2)/2)+(((N4-N2)/2)/16)* 15 degrees;

4) The division by 16 in the formula is because the light-emitting period of type A lidar is T=3.125μs, and the initial light-emitting time interval of each set of 16 channels in each data block is 50μs/3.125μs=16.

7.2.2 Horizontal Angle Calculation of Dual Echo Mode

In the dual echo data packet, a single-point laser emission obtains two returned data. Each pair of parity data blocks contains two measured values of 16 channels of the two sets of transmission time series, and each pair of parity data blocks returns only one azimuth angle. The angle value provided by the N-th odd-numbered block and the even-numbered block is the horizontal angle value corresponding to Channel 0 measured by the last laser emission, and the angle values corresponding to the other 31 channels need to be calculated by interpolation.

The data block structure of the C16 lidar’s dual-echo packet is as follows:

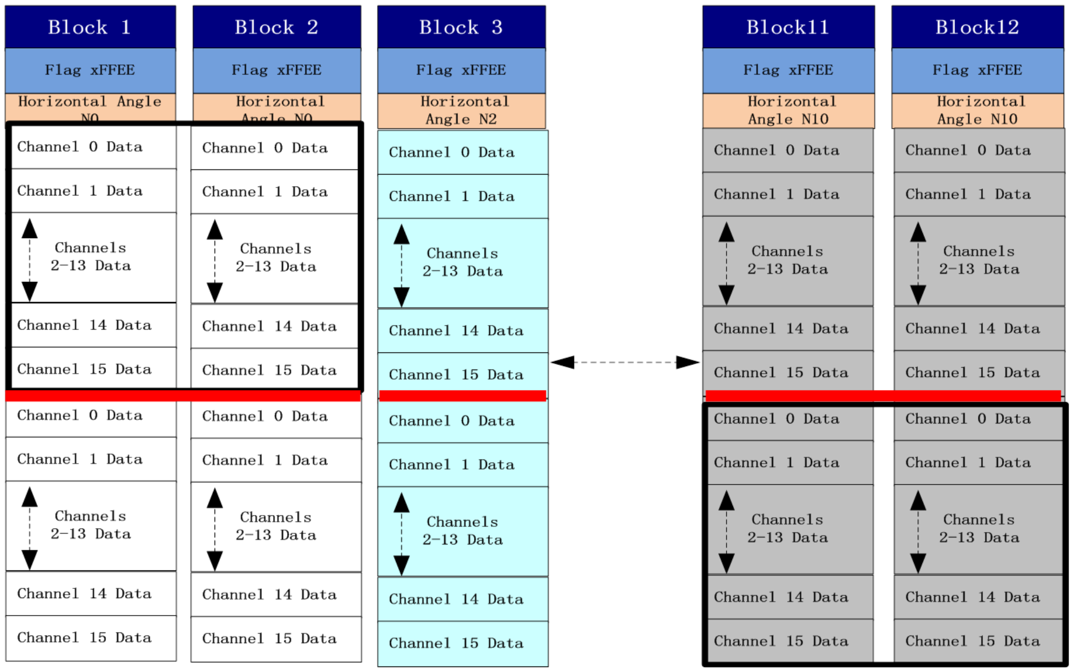

Figure 7.2 Dual Echo Data Block Structure

Take the second set of Channel 15 data of Block 3 as an example:

1) The light-emitting moment angle of Channel 0 of the first set of Block3 is N2 degrees;

2) The angle of deflection between the light-emitting moment of the second set of Channel 0 of Block 3 and the light-emitting moment of the first set of Channel

0 is (N2-N0)/2 degrees. Therefore, the angle of the second set of Channel 0's light-emitting moment is (N2+((N2-N0)/2)) degrees;

3) The time difference between the lighting time (T0+(15*T)) of the second set of Channel 15 of Block 3 and the lighting time T0 of the second set of Channel 0 is (15*T), the angle of deflection is (((N2-N0)/2)/16)*15 degrees. Therefore, the horizontal angle of the second set of Channel 15 light = the second set of Channel 0's light-emitting moment angle + deflection angle = (N2+(N2-N0)/2)+(((N2-N0)/2)/16)* 15 degrees;

4). The division by 16 in the formula is because the light-emitting period of type A lidar is T=3.125μs, and the initial light-emitting time interval of each set of 16 channels in each data block is 50μs/3.125μs=16.

7.3 Distance Value

Channel data distance calculation: obtain the 2-byte channel distance in the Little-Endian mode of the data packet, assuming it is 0x72,0x06, the hexadecimal number is expressed as 0x0672, the decimal number is 1650, and the unit is 0.25cm, then the distance is 1650X0. 25cm=412.5cm.

7.4 Cartesian Coordinate Representation

In order to obtain the vertical angle, horizontal angle and distance parameters of the lidar, the angle and distance information in polar coordinates can be converted to the x, y, z coordinates in the right-hand Cartesian coordinate system. The conversion relationship is shown in the following formula:

$$\begin{cases} x = r\cos\alpha\cos\theta; \\ y = r\cos\alpha\sin\theta; \\ z = r\sin\alpha \end{cases}$$

In the above formula, r is the distance, α is the vertical angle, θ is the horizontal rotation angle (the horizontal correction angle needs to be considered when calculating). And x, y, and z are the coordinates of the polar coordinates projected onto the x, y, and z axes.

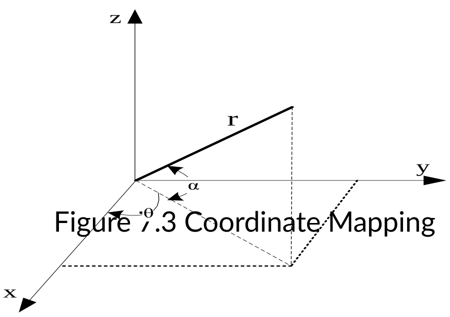

Figure 7.3 Coordinate Mapping

8. Accurate Time Calculation

To accurately calculate the time of the point cloud data, it is necessary to obtain the timestamp of the data packet and the UTC time of the device package output by the lidar. The timestamp and UTC time come from the same synchronization source, such as a GPS or NTP server.

The measurement time interval of each set of data in each data block of C16 lidar is 50μs. The data packet has 12 data blocks, and one data block contains 2 sets of 16-channel data.

A data packet has a total of (16*2) *12=384 channel data, and the packet packing time is about (50μs*2) *12=1.2ms, and the data rate is 1s/1.2ms=833.3 data packets/sec. Dual echo mode data rate doubled.

8.1 Calculation of Data Packet End Time

The timestamp in the data packet is a relative time in microsecond, which is defined as the packing time of the laser measurement data of the last channel in the data packet (packet end time), and its duration is less than 1 second. Therefore, to calculate the absolute end time of the data packet, it is necessary to obtain the 4-byte microsecond timestamp in the data packet first, and then obtain the UTC time (more than 1 second) from the device package. The addition of the two will be the exact time when the data packet ends.

8.2 Accurate Time Calculation of Channel Data

To obtain the accurate time of the end of the data packet, knowing that each of the 12 data blocks contains 2 sets of 16-channel light-emitting moments and the light-emitting time interval of each channel, the accurate measurement time of each channel data can be calculated.

8.2.1 End Time of Data Block

Each data block of the C16 lidar contains 2 sets of 16-channel measurement data. Therefore, the end time interval of each set of channels in each data block is 50us, and the end time interval of each data block (single echo mode) or each parity block pair (dual echo mode) is 2*50μs=100μs. Assuming that the absolute time of the end of the data packet is TPacket_end, the steps for calculating the end time of the data block TBlock_end(N) are as follows:

Single Echo Mode

The data packet contains 12 data blocks. In single echo mode, each data block includes 2 sets of single measurement data of 16 laser channels. The end time of each data block means that the 2 sets of 16 channels all end emitting light. The end time of each data block is calculated as follows:

TBlock_end(N) = (TPacket_end−100*(12-N)) μs. (N = 1,2,...,12) in which TBlock_end(N) represents the end time of the Nth data block.

Dual Echo Mode

The data packet contains 12 data blocks. In the dual echo mode, Block (1,2) corresponds to 2 echo measurement data of 2 sets of 16 laser channels. The odd block of each set of data represents one retrurn, and the even block represents the second echo. Block(3,4),...,Block(11,12) are the same. The end time of each block is calculated as follows:

TBlock_end(2N) = TBlock_end(2N-1) = (TPacket_end−100*(6-N)) μs. (N = 1,2,...,6)

In which, TBlock_end(M) represents the end time of the M-th data block, M=2N or (2N-1).

8.2.2 Calculate the Accurate Time of Channel Data

For C16 lidar with a vertical angle of 2 degrees, the light-emitting time interval of each channel is fixed as: T=50μs/16=3.125μs. The light-emitting time has a fixed correspondence with the encapsulation order of UDP packets. Assuming that the light-emitting time of Channel 0 is T0, the corresponding 16-channel light-emitting time is shown in the following table:

Table 8.1 C16 Lidar Channel Light-Emitting Time

UDP Packet Encapsulation Sequence (Channel)	Vertical Angle	light-emitting time (T=3.125μs)
Channel 0 Data	-15°	T0
Channel 1 Data	1°	T0+(1*T)
Channel 2 Data	-13°	T0+(2*T)
Channel 3 Data	3°	T0+(3*T)
Channel 4 Data	-11°	T0+(4*T)
Channel 5 Data	5°	T0+(5*T)
Channel 6 Data	-9°	T0+(6*T)
Channel 7 Data	7°	T0+(7*T)

Channel 8 Data	-7°	T0+(8*T)
Channel 9 Data	9°	T0+(9*T)
Channel 10 Data	-5°	T0+(10*T)
Channel 11 Data	11°	T0+(11*T)
Channel 12 Data	-3°	T0+(12*T)
Channel 13 Data	13°	T0+(13*T)
Channel 14 Data	-1°	T0+(14*T)
Channel 15 Data	15°	T0+(15*T)

After the end time of each data block is obtained, the precise measurement time of the point cloud data of each channel in the data block can be calculated according to the corresponding relationship between the channel data packing sequence and the light-emitting time in the above table.

Take the calculation of the data time TB3G1C3 of Channel 3 in the first set of Block 3 in single return mode as an example:

1) Calculate the end time of the data packet, obtain the microsecond timestamp TTimestamp from the data packet, obtain the UTC time TUTC from the device package, and the end time of the data packet TPacket_end = TTimestamp + TUTC;

2) Calculate the end time of Block 3 TBlock_end(3) = (TPacket_end–100μs*(12-3)) = (TPacket_end- 900)μs = (TTimestamp + TUTC-900)μs, which is also the Channel 15 time of the second set of Block 3. Among which, 100μs represents the time interval for each block to end the light emission.

3) Between the lighting time of Channel 3 in the first set of Block 3 (T0+(T*3)) and the lighting time of Channel 15 in the second set (16*T+ (T0+(T*15))) , the difference is (16*T+(T*(15-3))) = 28 light-emitting cycles. Therefore, the accurate time of this channel data TB3G1C3 = (TBlock_end(3)-28*T)μs = ((TTimestamp + TUTC-900) -28*3.125)μs. Among which, 16*T is the end time interval of each set of channels in each data block.

Take the calculation of the data time TB3G1C3 of Channel 3 in the first set of Block 3 in the dual echo mode as an example:

1) Calculate the end time of the data packet, obtain the microsecond timestamp TTimestamp from the data packet, obtain the UTC time TUTC from the device package, and the end time of the data packet TPacket_end = TTimestamp + TUTC;

2) Calculate the end time of Block 3 TBlock_end(3) = (TPacket_end–100*(6-2))μs

= (TPacket_end- 400)µs = (TTimestamp + TUTC-400)µs, which is also the Channel 15 time of the second set of Block 3. Among which, 100µs represents the time interval at which each parity block pair ends to emit light.

3) Between the lighting time of Channel 3 of the first set of Block 3 (T0+(T*3)) and the lighting time of Channel 15 of the second set (16*T+(T0+(T*15))), the difference is (T*(16+15-3)) = 28 lighting cycles. Therefore, the accurate time of this channel data TB3G1C3 = (TBlock_end(3)-28*T)µs = ((TTimestamp + TUTC-400)-28* 3.125)µs. Among which, 16*T is the end time interval of each set of channels in each data block.

Revision History

Rev.	Release Date	Revised Content	Issued/Revised By
V3.5.0	2021-11-26	Initial Version	LS1286
V3.5.1	2022-01-11	Aviation Plug Cable Length	LS1286
V3.5.2	2022-04-22	Parameter; Layout adjustment	LS1286

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