LSLIDAR

The Leader In LiDAR Industry

C16 operating manual

2019.08.30

V2.0

en.leishen-LiDAR.com

LiDAR Description

Description

1. All the illustrations in this instruction are for reference only and shall be subject to the latest products.

2. In order to avoid violating the warranty terms, it is not allowed to disassemble the LiDAR. For the relevant operation, please consult LeiShen Intelligent's after-sales technical staff.

Operating principles

Ranging principle of C16 series multi-line hybrid solid-state LiDAR Time of flight measurement Time of flight: As the laser transmitter emits a laser pulse, the internal timer starts to calculate the time (t_1) and stops (t_2) when the laser receiver receives the partial energy of the laser wave bouncing off any objects

Distance = Light Speed × (t_2-t_1)/2

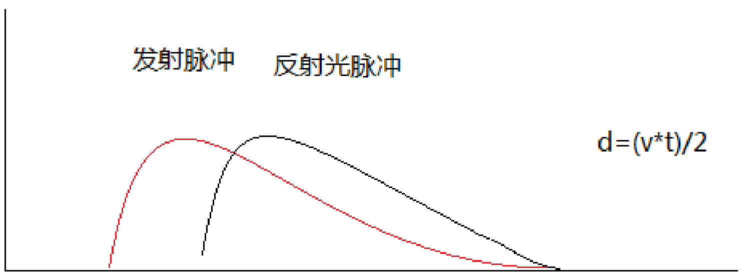


Figure 1 Principle of Measurement

Structure and parameter

Description of Structure

Inside the LiDAR enclosure are 16 pairs of laser-emitting and receiving devices mounted on the bearings. A 360-degree panoramic scan is done by rotating the internal motor at 5Hz (or 10Hz, 20Hz).

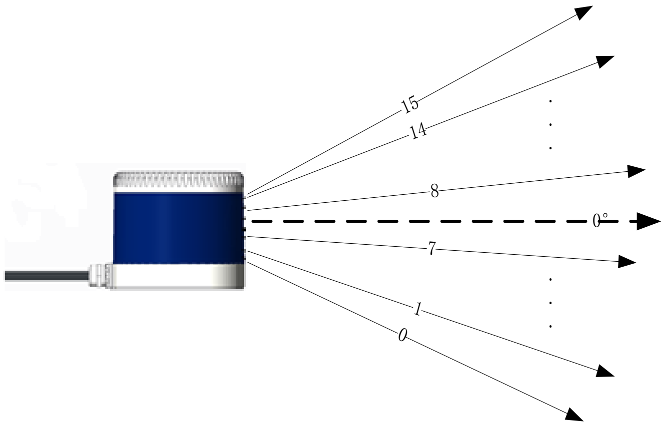


Figure 2 C16-xxxB/CExterior Structure Diagram

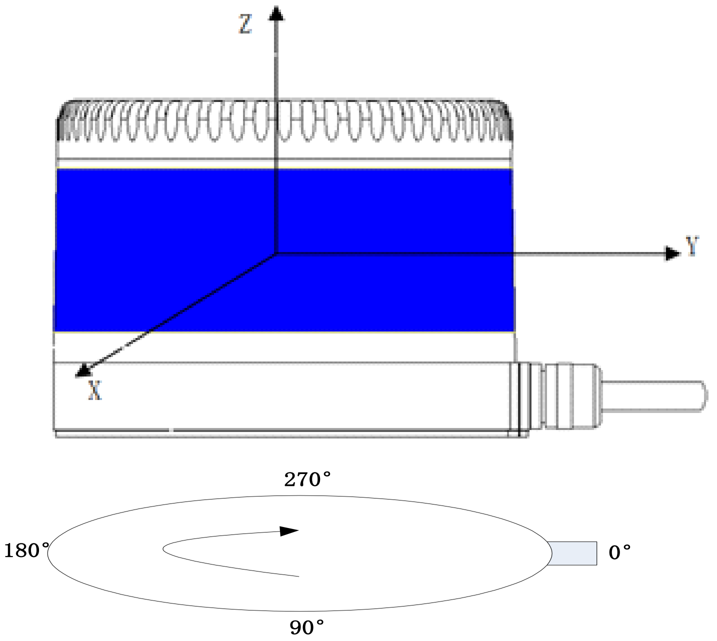


Figure 3 C16 series LiDAR Coordinate system and scanning direction

Specification

Table 1 : Specifications of LeiShen Intelligent 16 lines LiDAR C16-xxxB

<table>
<tr><td colspan="2">Model</td><td colspan="4">C16-xxxB</td></tr>
<tr><td colspan="2">Detecting way</td><td colspan="4">Pulsed Laser</td></tr>
<tr><td colspan="2">Laser band</td><td colspan="4">905nm</td></tr>
<tr><td colspan="2">Laser class</td><td colspan="4">Class 1 (eye-safe)</td></tr>
<tr><td colspan="2">Laser channel</td><td colspan="4">16-channel</td></tr>
<tr><td colspan="2">Detecting range</td><td>70m</td><td>120m</td><td>150m</td><td>200m</td></tr>
<tr><td colspan="2">Range accuracy</td><td colspan="4">±3cm</td></tr>
<tr><td colspan="2">Data acquisition speed (Dual return mode)</td><td colspan="4">320,000 pts/sec
(640,000 pts/sec)</td></tr>
<tr><td rowspan="2">FOV</td><td>Vertical</td><td colspan="4">-16° ~+15°</td></tr>
<tr><td>Horizontal</td><td colspan="4">360°</td></tr>
<tr><td rowspan="2">Angular Resolution</td><td>Vertical</td><td colspan="4">(2° equal)</td></tr>
<tr><td>Horizontal</td><td colspan="4">5Hz: 0.09°
10Hz: 0.18°
20Hz: 0.36°</td></tr>
<tr><td colspan="2"></td><td colspan="4">5Hz, 10Hz, 20Hz(optional)</td></tr>
</table>

Scanning speed	
Communication interface	Ethernet external communication, PPS
Supply scope	+9V～+36VDC
Operating temperature	-10℃～+60℃
Storage temperature	-40℃～+85℃
Impact	500 m/sec^2 , for 11 ms
Vibration	5Hz～2000Hz,3G rms
IP Grade	IP67
Dimension	Φ 102mm*78mm
Weight	1050g(including 1.2m cable)/840g(lightweight, including 1.2m cable)

Table 2: Specifications of LeiShen Intelligent 16 lines LiDAR C16-xxxC

Mode	C16-xxxC
Detecting way	Pulsed Laser
Laser band	905nm

Laser class		Class 1 (eye-safe)			
Laser channel		16-channel			
Detecting range		70m	120m	150m	200m
Range accuracy		±2cm			
Data acquisition speed (Dual return mode)		320,000 pts/sec (640,000 pts/sec)			
Viewing Angle	Vertical	-10° ~+10°			
	Horizontal	360°			
Angle Resolution	Vertical	Equal 1.33° (equal)			
	Horizontal	5Hz: 0.09º 10Hz: 0.18º 20Hz: 0.36º			
Scanning speed		5Hz, 10Hz, 20Hz(optional)			
Communication interface		Ethernet external communication, PPS			
Supply scope		+9V～+36VDC			
Operating temperature		-10℃～+60℃			

Storage temperature	-40℃～+85℃
Impact	500 m/sec^2 , for 11 ms
Vibration	5Hz～2000Hz,3G rms
IP Grade	IP67
Dimension	Φ 102mm*78mm
Weight	1050g(including 1.2m cable)/840g(lightweight, including 1.2m cable)

External Dimensions and installation

There are 2 positioning holes and 4 M4 screw mounting holes at the bottom of the LiDAR. The data line interface position is 0 degree horizontal angle of the LiDAR, and the LiDAR rotates clockwise.

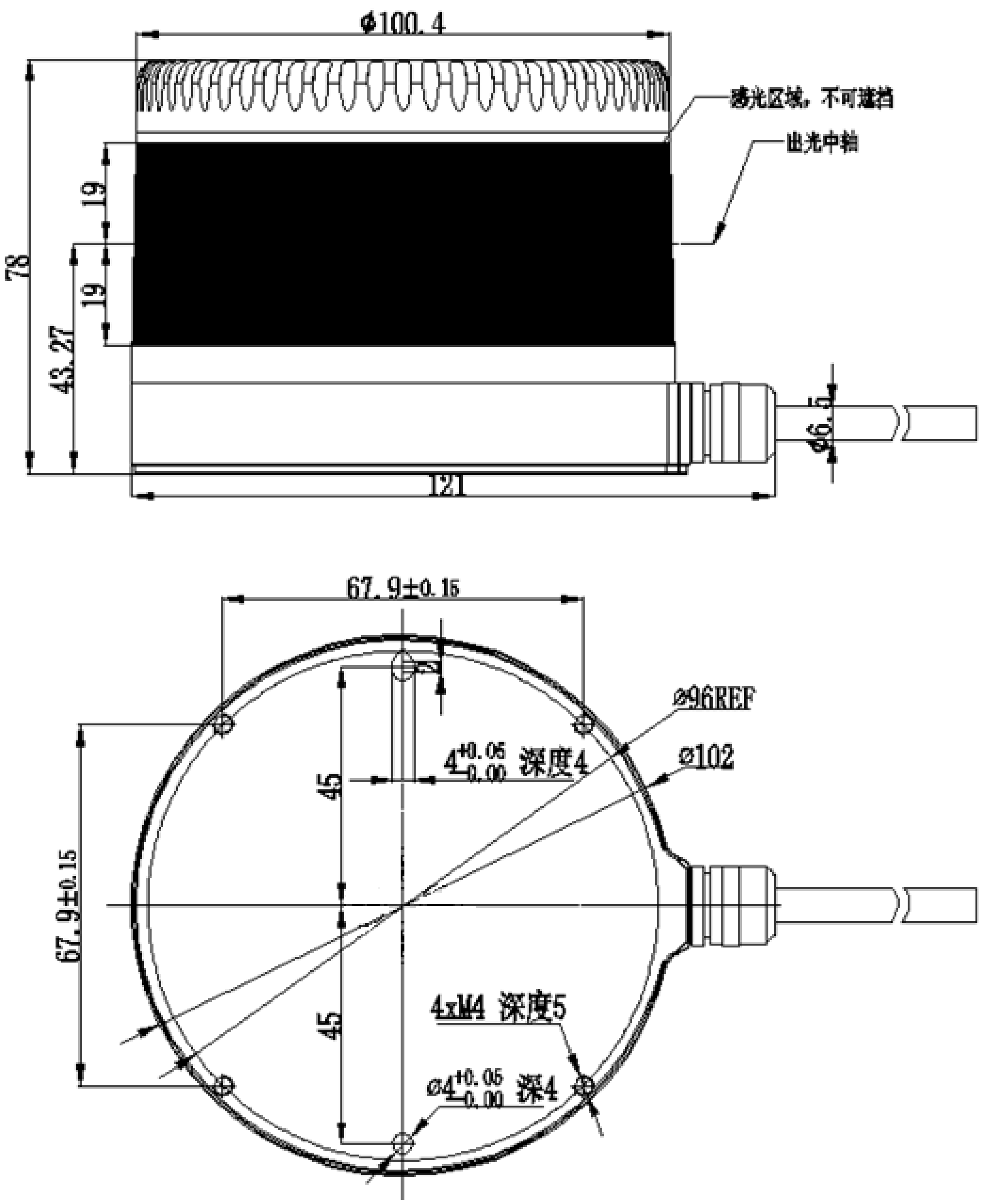


Figure 4 Structure size of 16-line B/C type LiDAR

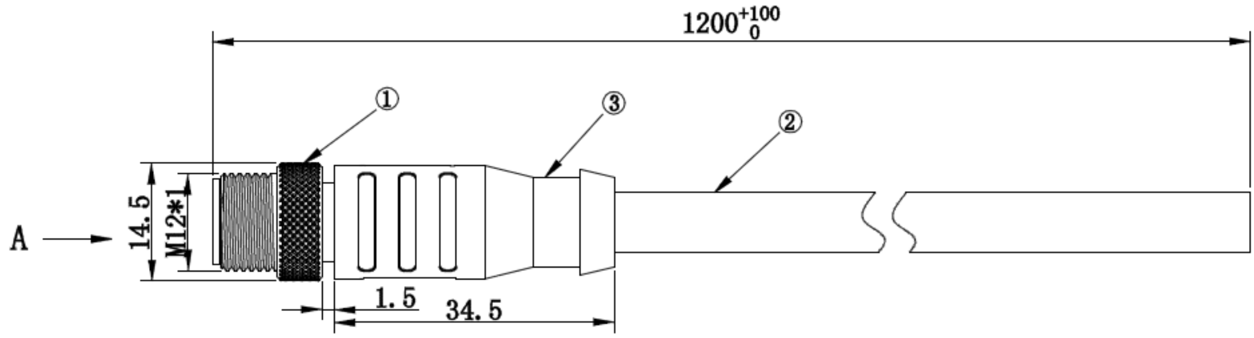
Electrical interface

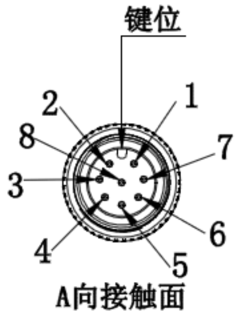
Device power supply

Device power supply input range: 9VDC - 36VDC, use of input voltage 12VDC recommended.

Definition of device lead output interface

C16 series multi-line LiDAR body leads cable (8-core shielded wire with serial number shown as below) from the side at the lower side.

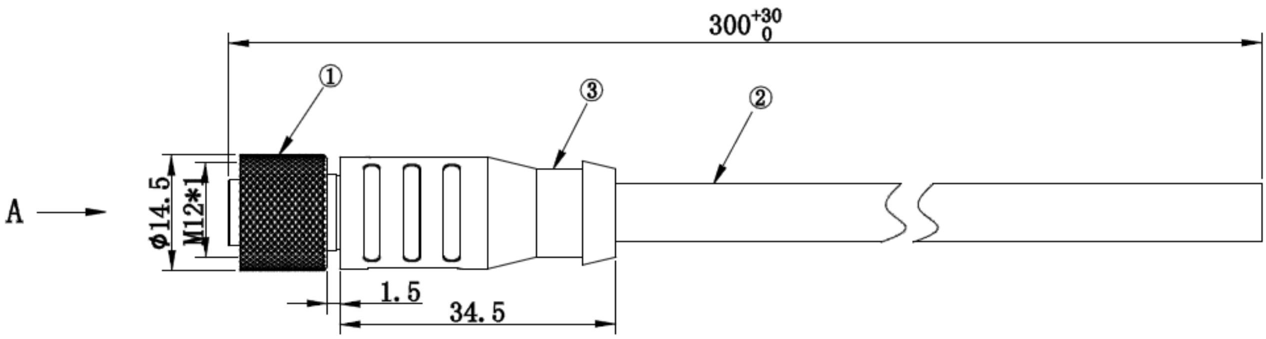


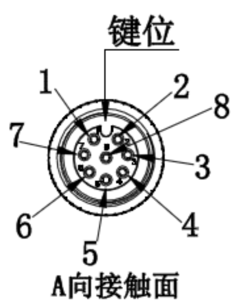


接线定义

母头	线色
1	黑
2	浅蓝
3	蓝
4	浅橙
5	橙
6	黄
7	白
8	红
铁壳	屏蔽

The terminal block wire number is as shown below





接线定义

公头	线色
1	黑
2	浅蓝
3	蓝
4	浅橙
5	橙
6	黄
7	白
8	红
铁壳	屏蔽

表 3：8 core cable defined as follows：

S/N	Cable color and specifications	Definition	Description
1	Red（20AWG）	VCC	Positive power supply
2	Light blue（24AWG）	TD_N	Negative Ethernet transmitter differential
3	Blue（24AWG）	TD_P	Positive Ethernet transmitter differential
4	Light orange（24AWG）	RD_N	Negative Ethernet receiver differential
5	Orange（24AWG）	RD_P	Positive Ethernet receiver differential
6	Yellow（20AWG）	GPS_PPS	GPS synchronous second pulse / external synchronous second pulse
7	White（20AWG）	GPS_Rec	GPS timing receiving
8	Black（20AWG）	GND	Negative power supply (GND)

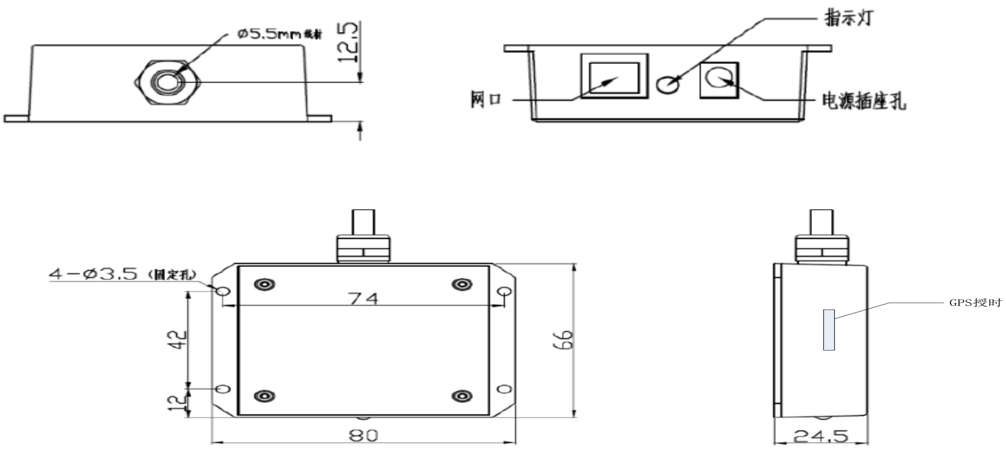
Users can use the C16 series multi-line LiDAR to move the 8-pin terminal wire out of the junction box. The junction box provides three interfaces: power supply, Ethernet RJ45 interface and GPS device interface. Simply open the junction box housing and disconnect the soldering position of the core cable, remove the 8-pin terminal cable connector from the junction box. The purpose of the junction box is to allow the user to directly use the power adapter, Ethernet cable, and 6-pin GPS connector that comes with the LiDAR.

C16 series multi-line LiDAR factory default connection junction box, from the LiDAR to junction box line length is divided into two sections, cable which connected to the LiDAR part of 1.2 meters, the connection junction box line length of 0.3 meters, the middle aviation plug connection, as shown.

图 6 接线盒与雷达连接示意图

Figure 6 Connection between Adapter Box and LiDAR

The adapter box for the C16 series multi-line LiDAR has external interfaces including: 2.1MM DC socket, indicator, 100M Ethernet RJ45 port, and the 6-pin connector GPS timing interface.



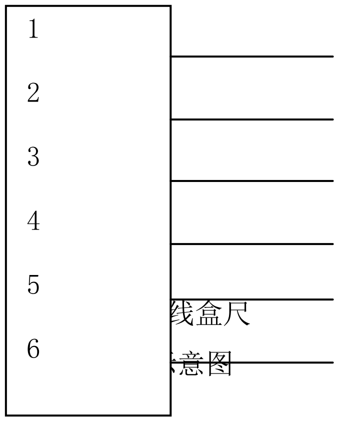


Figure 7 Junction box size and interface diagram

GPS interface

Table 8 Terminal Block Definition

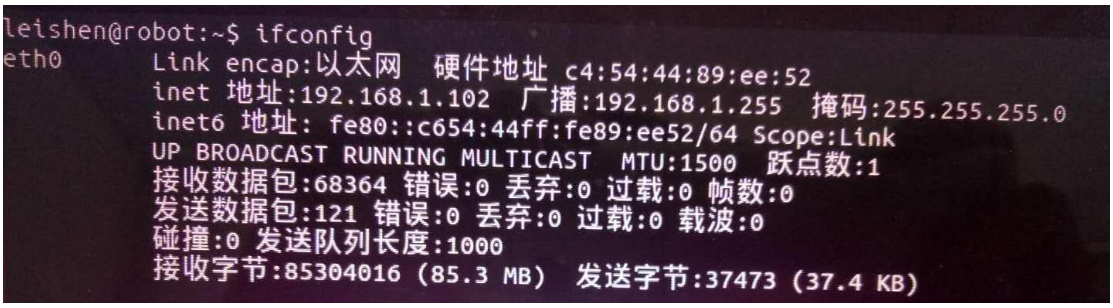
Interface S/N	Description
1	GPS_PPS
2	+5V input
3	GND

4	GPS_REC
5	GND
6	NC

ROS Intructions

Hardware connection and testing

Connect LiDAR network interface and power cord Set the computer IP based on the target IP on LiDAR (use the ifconfig command to see if the computer IP has been set successfully, as shown in the target IP 192.168.1.102)

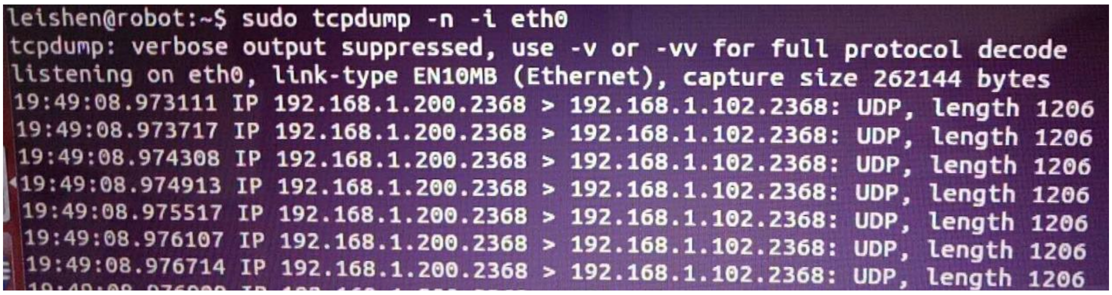


Note: LiDAR factory set IP:192.168.1.102 as original, please configure LiDAR IP according to the actual IP on the computer.

After the LiDAR is powered on, observe whether the computer's wired connection icon is connected properly or not.

Open terminal: ping LiDAR IP, test whether the hardware connection is normal. if the ping dose not show well, check the hardware connection

You can further use: sudo tcpdump-n-i eth0, (where eth0 is the name of the wired network device.Please refer to the name of the display device which is connected by ifconfig wired) to check the LiDAR data packets (as shown in the diagram showing the LiDAR sending 1206 bytes to the destination packet which means the LiDAR data is transmitted successfully)



Note: after setting up ip for the first time, please restart the LiDAR.

Software operation example

Create a workspace and build a compilation environment

mkdir -p ~/leishen_ws/src

cd ~/leishen_ws

> 备注：
>
> 工作空间可以任意命名，例如 leishen_ws 可以改成任意命名。

Download LiDAR drive and dependency packets

> 备注：
>
> 驱动和依赖包也可以直接从我司网站或客服处获取，将获取到的 lsLiDAR_c16_V1.01.180118.tar 拷贝到新建立的工作空间 turtlerot_ws/src 下，使用 tar －xvf lsLiDAR_c16_V1.01.180118.tar 命令解压缩即可

Compile package

cd ~/leishen_ws

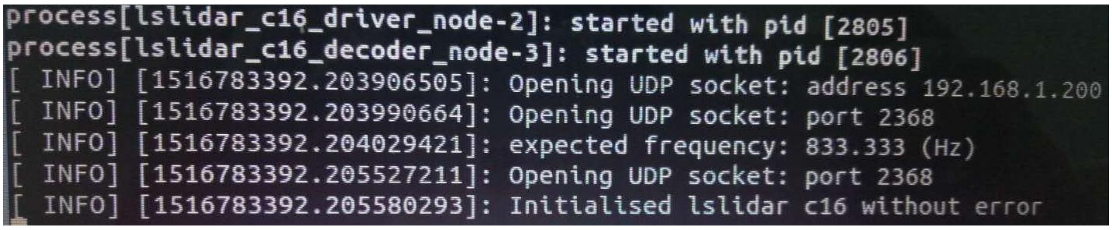
catkin_make

Running program

source ~/leishen_ws /devel/setup.bash

roslaunch lsLiDAR_c16_decoder lsLiDAR_c16.launch --screen

Note: if you have modified the LiDAR destination port and speed, please open the lsLiDAR_c16.launch to modify the configuration, the default port is 2368, the speed of 10hz is 2000 points.



```
process[lslidar_c16_driver_node-2]: started with pid [2805]
process[lslidar_c16_decoder_node-3]: started with pid [2806]
[ INFO] [1516783392.203906505]: Opening UDP socket: address 192.168.1.200
[ INFO] [1516783392.203990664]: Opening UDP socket: port 2368
[ INFO] [1516783392.204029421]: expected frequency: 833.333 (Hz)
[ INFO] [1516783392.205527211]: Opening UDP socket: port 2368
[ INFO] [1516783392.205580293]: Initialised lslidar c16 without error
```

Note: if the timeout indicates that the driver has no data, please check the hardware connection. Open a terminal again and execute the following command:

rosrun rviz rviz

备注：

如果 1,2,3 步已完成，下次再重新打开 Displays 窗口时，只需要从第 4 步开始执行即可

5. Display the data detected by LiDAR in the pop-up displays window.

Please change the value of "Fixed Frame" to “laser_link”, click the “add” button, and click “pointcloud2” under “by topic” to add the multi-lines point cloud.

Software Instructions

Introduction

This document is intended to guide users and developers how to use the 16-line LiDAR of LeiShen Intelligent System Co., Ltd. and the matching 16-line LiDAR display software.

Application scope

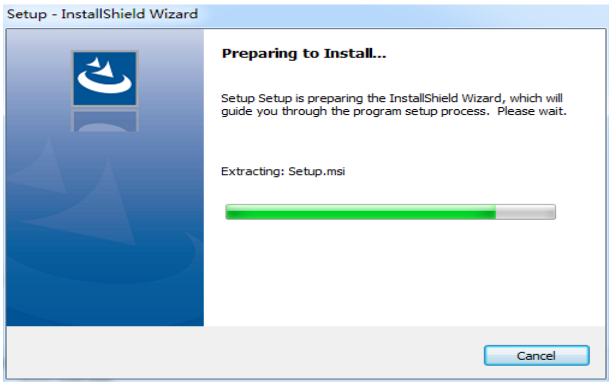
The multi-line LiDAR display software of LeiShen Intelligent is applicable for the 16-line LiDAR of LeiShen Intelligent and compatible with the related operations of 16-line single and second echo LiDAR of Velodyne.

Software installation

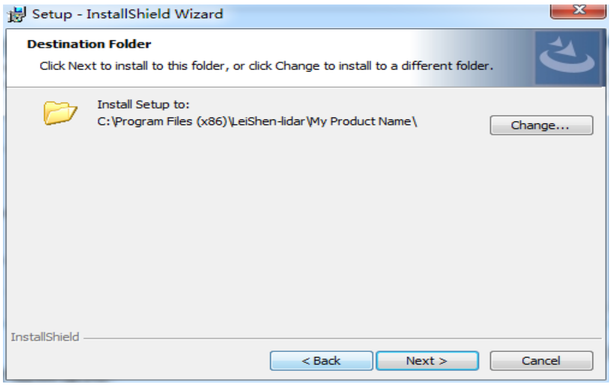
1. Installation environment

This software is currently only applicable in the Windows x64 system operating platform. The configuration requirements for the computer installing the software are: CPU: Intel (R) Core(TM) i5 or above, GPU: NVDIA GeForce GTX750 or above (most desirable), or it may influence the software display effect. After installing Leishen's multi-lines software, it still needs to install WinPcap, from the third-party library, which is enclosed in Leishen's multi-lines software.

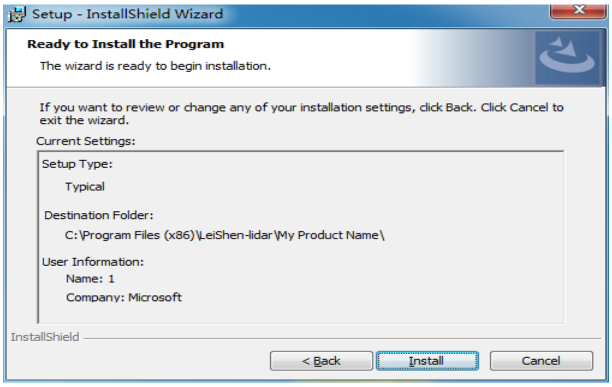
2. Insert the CD-ROM for software installation included with the LiDAR into the CD/DVD drive. Open the CD-ROM and double-click  to install the file and the installation interface will pop up.

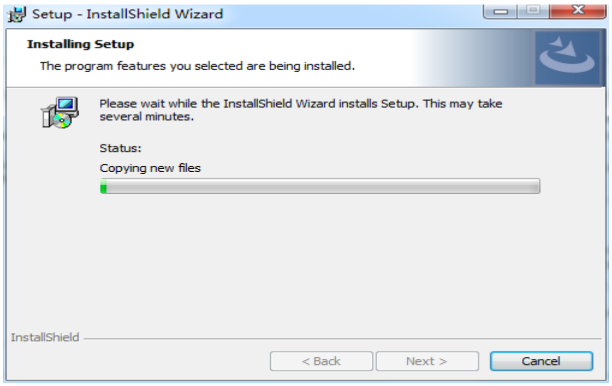


3. Click next to enter the installation path selection interface.



4.After customizing the installation path (do not use a path in Chinese), click next to enter the installation interface and click the install button. Wait until the installation is completed.

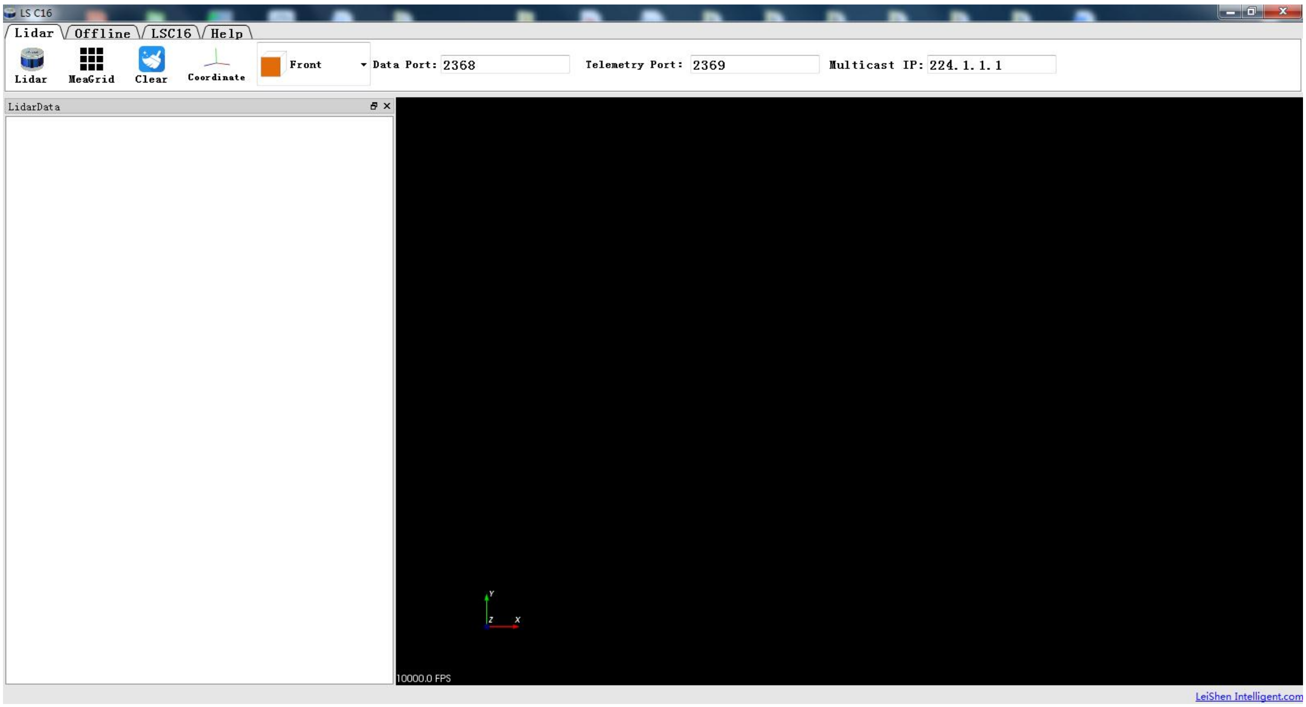




Introduction and use of related functions

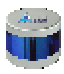
Operation of multi-line LiDAR display system of LeiShen Intelligent

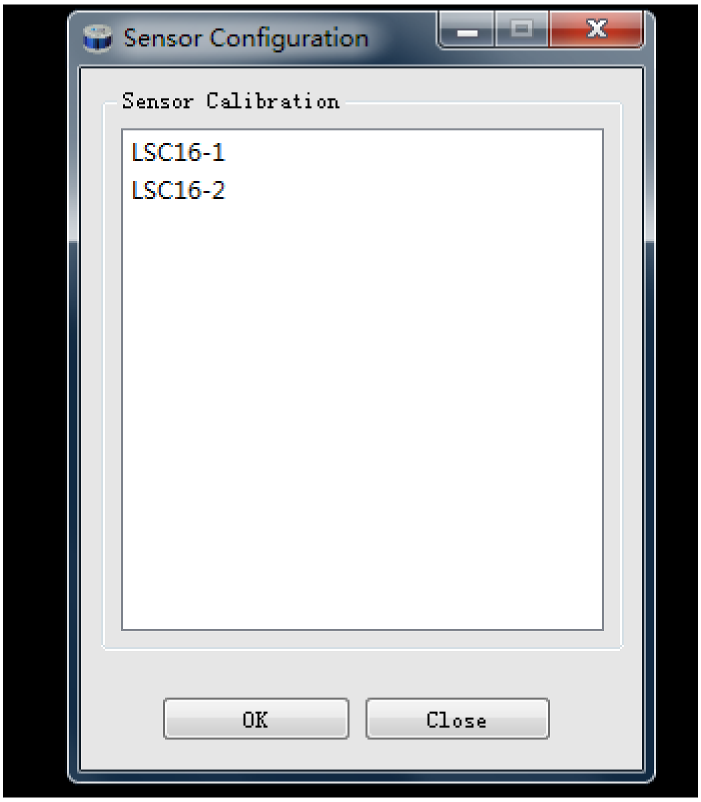
Double-click the shortcut icon on the desktop: The initial interface is shown below:

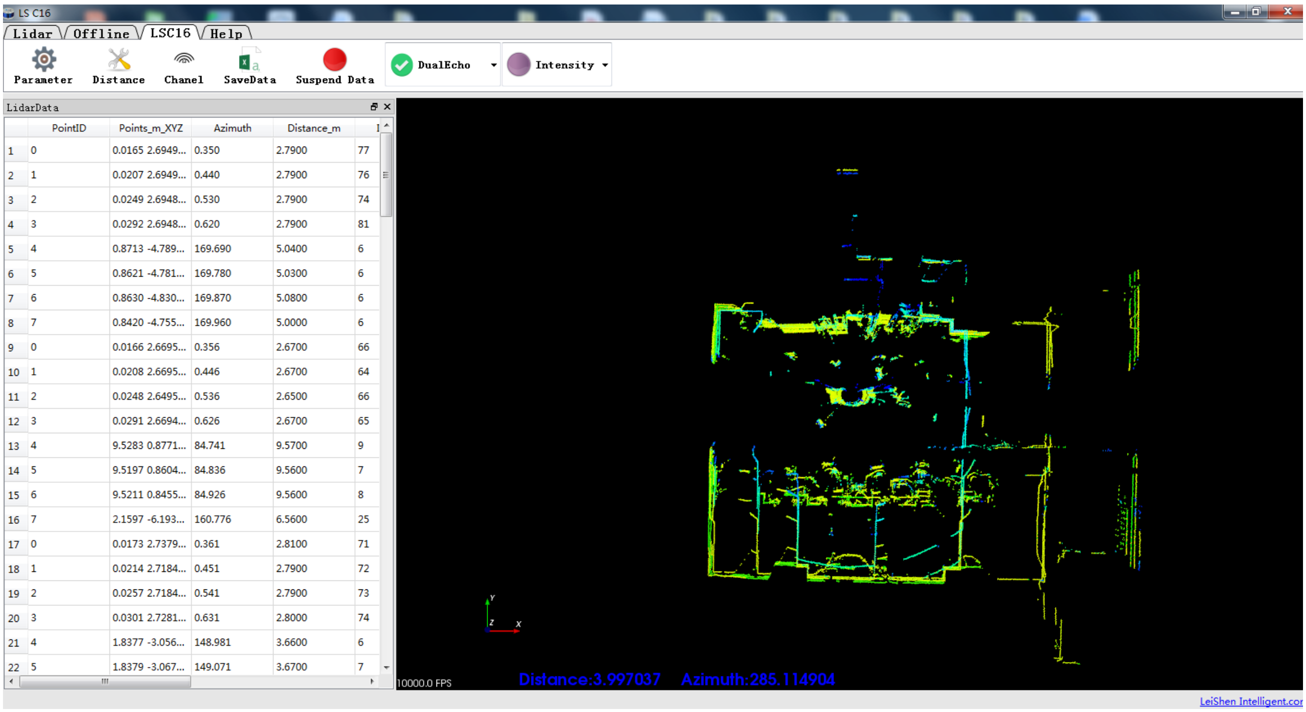


1) Introduction of Real-time LiDAR data receive button

setting data port number (default 2368) ,telemetry port(default 2369)

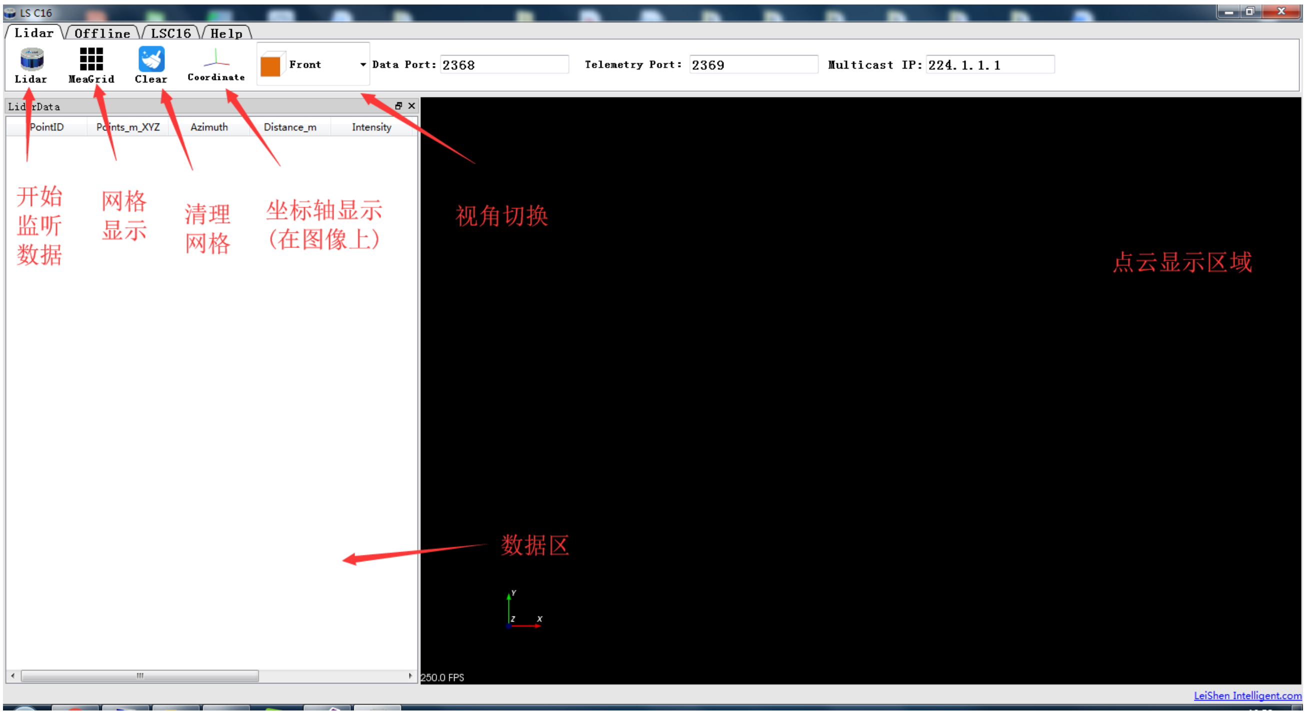
When LiDAR's power supply is connected to the network cable, click on to get real-time receiving LiDAR data. Click on “Confirm” button on interface to check whether the software automatically detects the received data or not. It also can check real time data and display condition. If click “Cancel”,no LiDAR date shows. Select LSC16(single channel) or LSC16-2(dual channel) data to display directly.





Software interface related introduction:

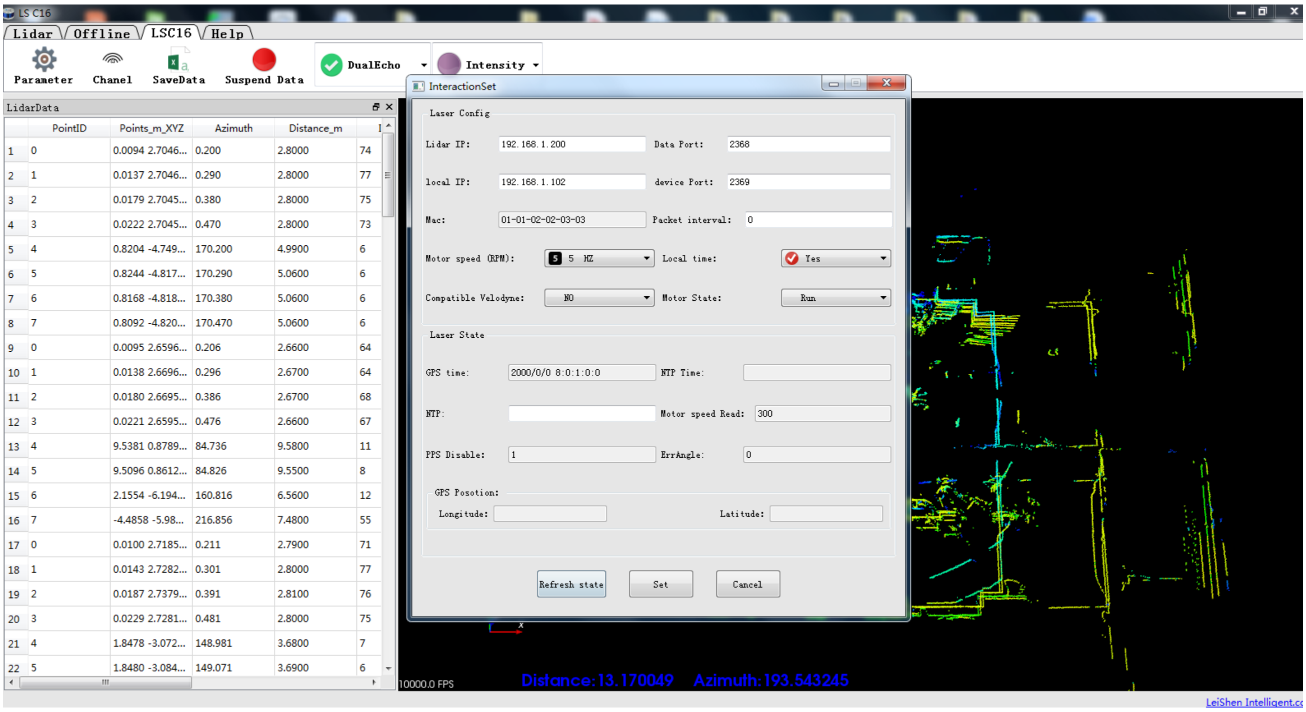
The software interface includes menu area, toolbar area, 3D window area, data table area, play frame information area, company website link and so on. The sections are shown in the following figure.



The data sheet contains (PointID, Points_m_XYZ, adjusted time, Azimuth, Distance, Intensity, Laser_id, timestamp). In particular, Point ID is the point number, Points_m_XYZ is coordinate of the space x, y and z. Azimuth is the azimuth, Distance the distance, Intensity the reflection intensity, Laser_id the LiDAR channel, adjusted time the adjusted time, and timestamp the time stamp.

User configuration write

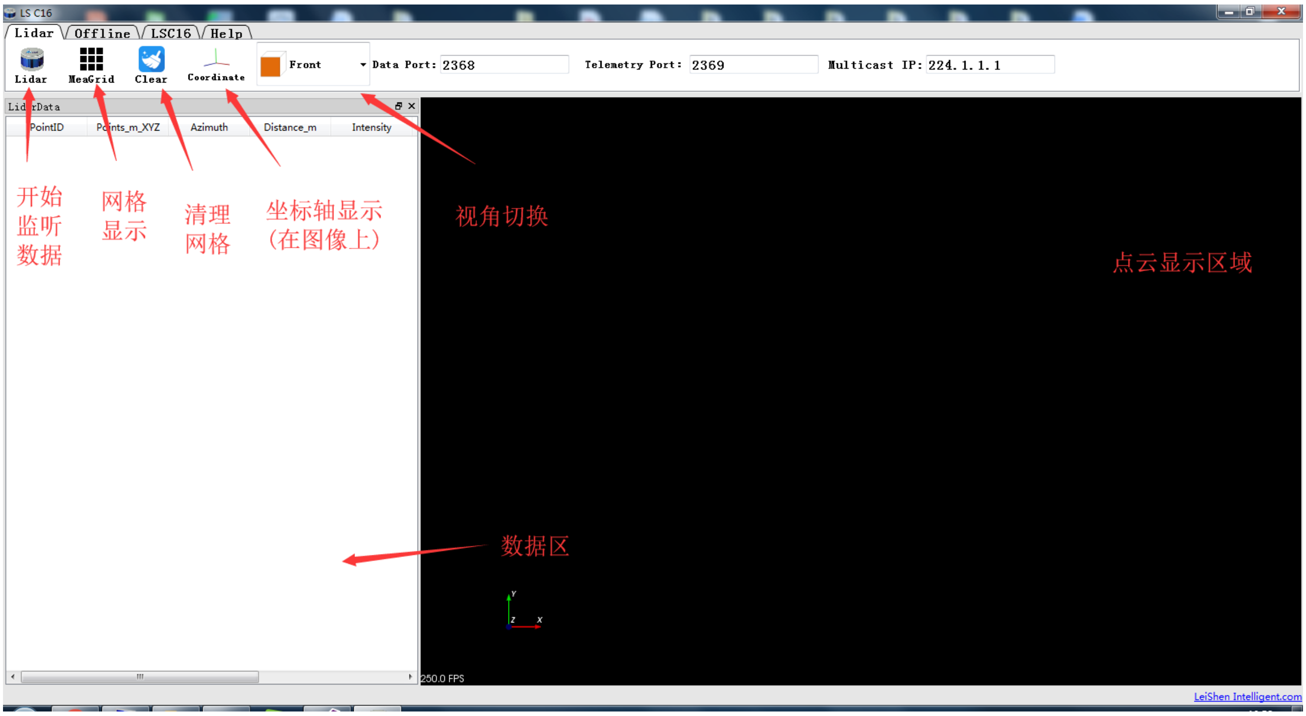
Click the icon  to pop up the LiDAR parameter setting form as shown below, where it is possible to set the relevant LiDAR.



LiDAR parameter setting is in the upper section of the form, where it is possible to set such parameters as LiDAR local IP, LiDAR destination IP, LiDAR local port, LiDAR destination port, LiDAR speed setting, get local time or not, and Mac address information. Users can also set "compatible with Velodyne or not" (the device information stream packet is not sent with the main data stream), and "stop LiDAR or not" (the third item under the combobox option offers choice whether to send the current LiDAR speed information; if it is selected, distance will no longer be shown in the distance column and is replaced by speed value). The LiDAR real-time status information is in the lower section. The DIFOP status packet sent periodically according to the LiDAR shows its current status information, including GPS location information, satellite time information, motor speed, current LiDAR IP, and the current LiDAR port number.

Clicking the Status Information Refresh allows to get the previous configuration information of the LiDAR (content of device information stream). After filling in the setting information, click the Settings button to send the UCWP packet to the LiDAR. When the LiDAR receives the UCWP packet, it is necessary to disconnect the power for the settings to take effect.

LiDAR menu

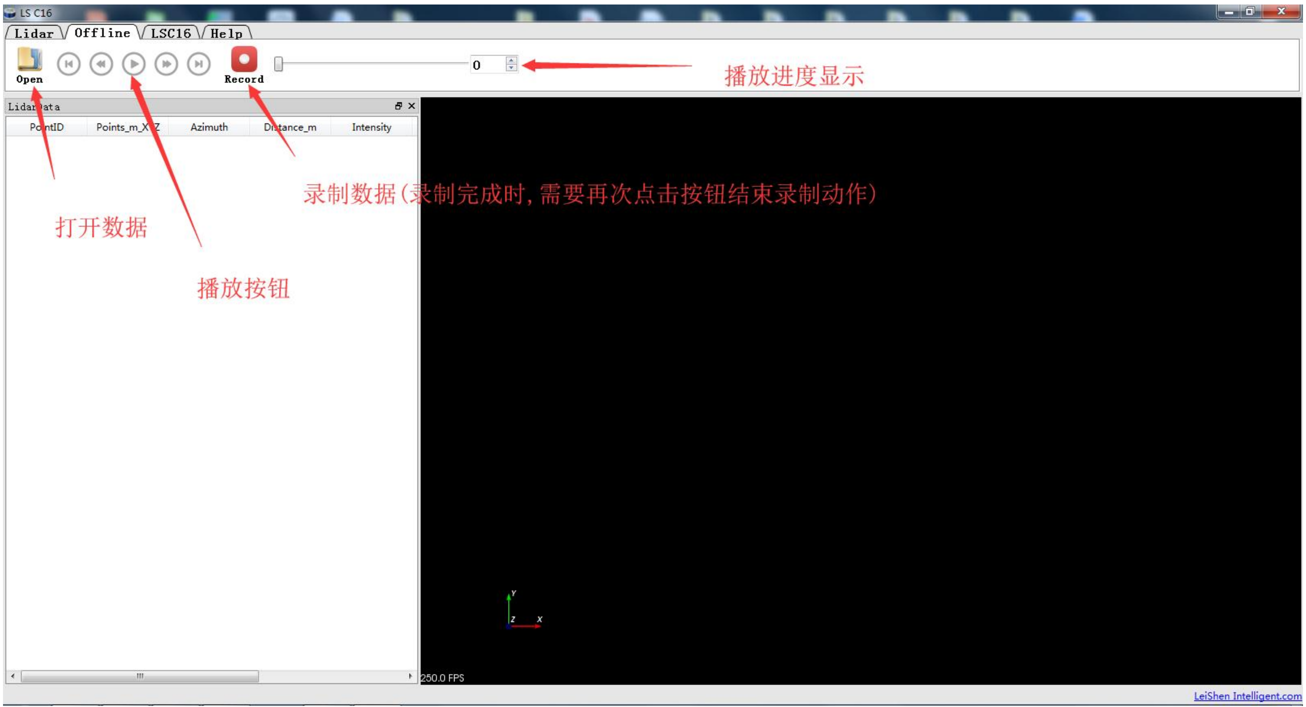


Offone menu

Click Button, select LiDAR type.

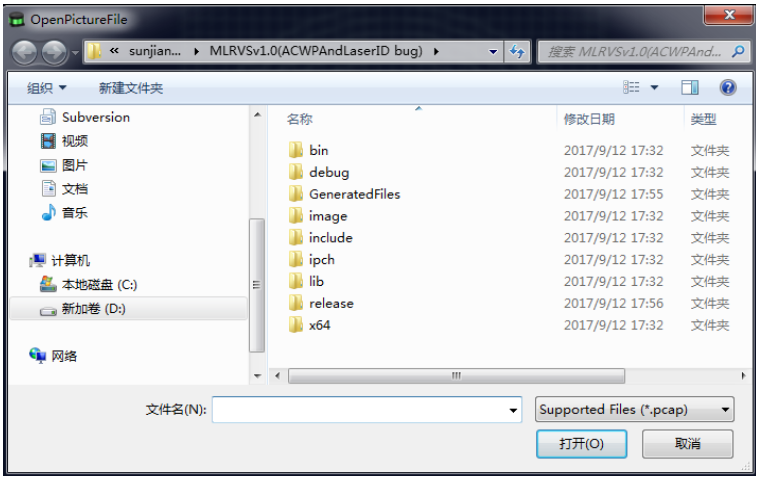
Clickbutton, open offline data.

Clickbutton, start saving offline data, valid when LiDAR receives data in real time.



Play pcap offline point cloud

Click  button to pop up the dialog box:



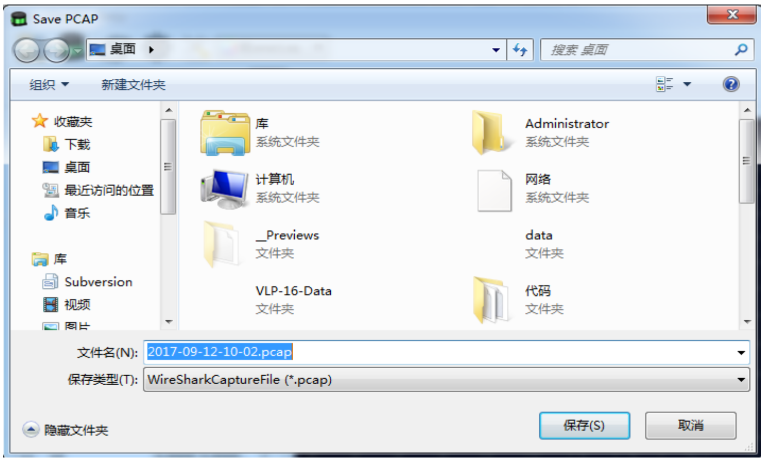
Select the pcap file you want to play and click the Open button.

Click  button, chose LSC16 data to connect display, Start play offline point cloud pcap files and visualize point cloud data.

Introduction of play related buttons

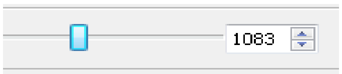
For the play/pause button, a pause is enabled by clicking  when it is playing and playback resumes by clicking  when it is paused.

Clicking the button  stores data and records pcap point cloud file. This function can only be used when the LiDAR data is received in real time and in playback mode. After clicking, the pcap file storage dialog will pop up and storage starts after the path is selected, as shown below:



Clicking  again stops storing.

Note: When an offline pcap file is playing, the button is gray and the function is disabled.



The progress bar in the toolbar shows the progress of the playing file, with the data in the input box being the number of frames at which the file is playing.

Introduction of point cloud display

In the point cloud data, there are 20 circles and 40 × 40 grids in the display box. There is a distance of 10m between the radius of two neighboring circles and 10m between two grids (horizontal or vertical). The radius of the outermost circle is 200m. Grids and auxiliary circles make it easy for users to see the location of point cloud.

3D Display the orientation of the interface axes with XY on the axis of the point cloud reference system xyz Axis in the same direction.

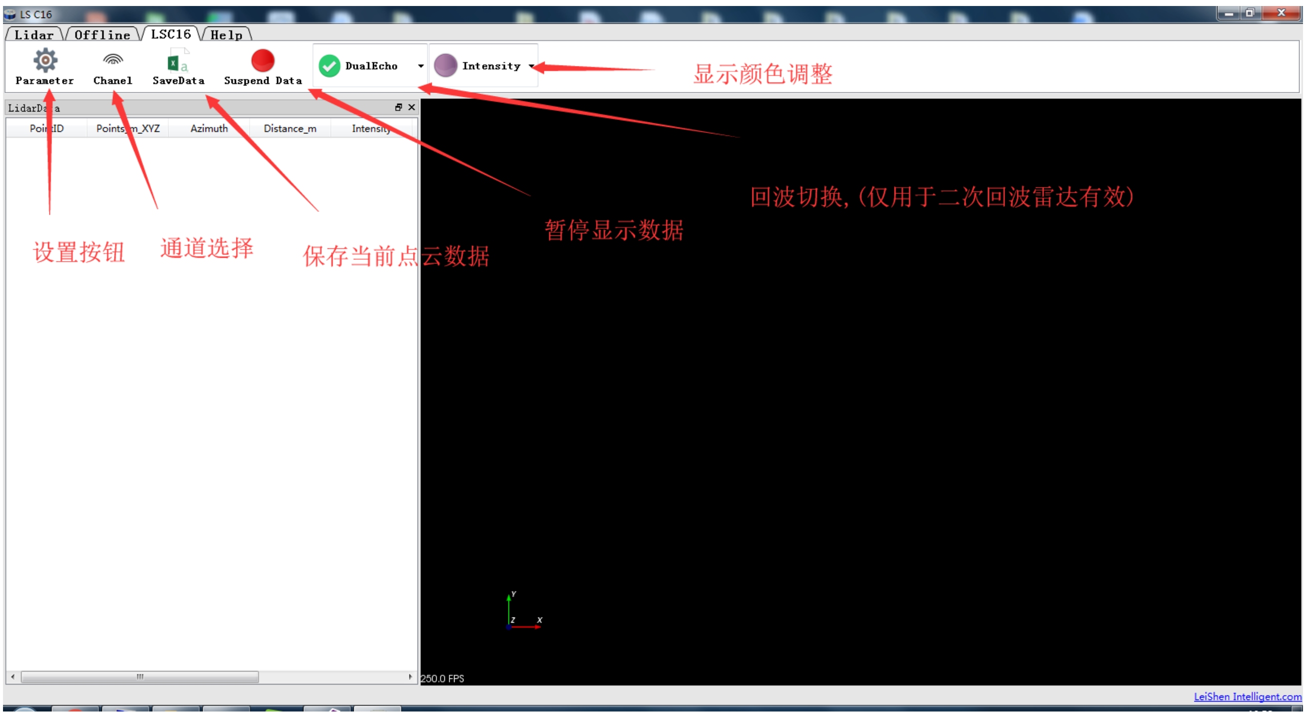
Point cloud display interface supports the following operations:

1. By moving the mouse wheel the display interface zooms in/out; holding down the right mouse button to drag up/down can also do.

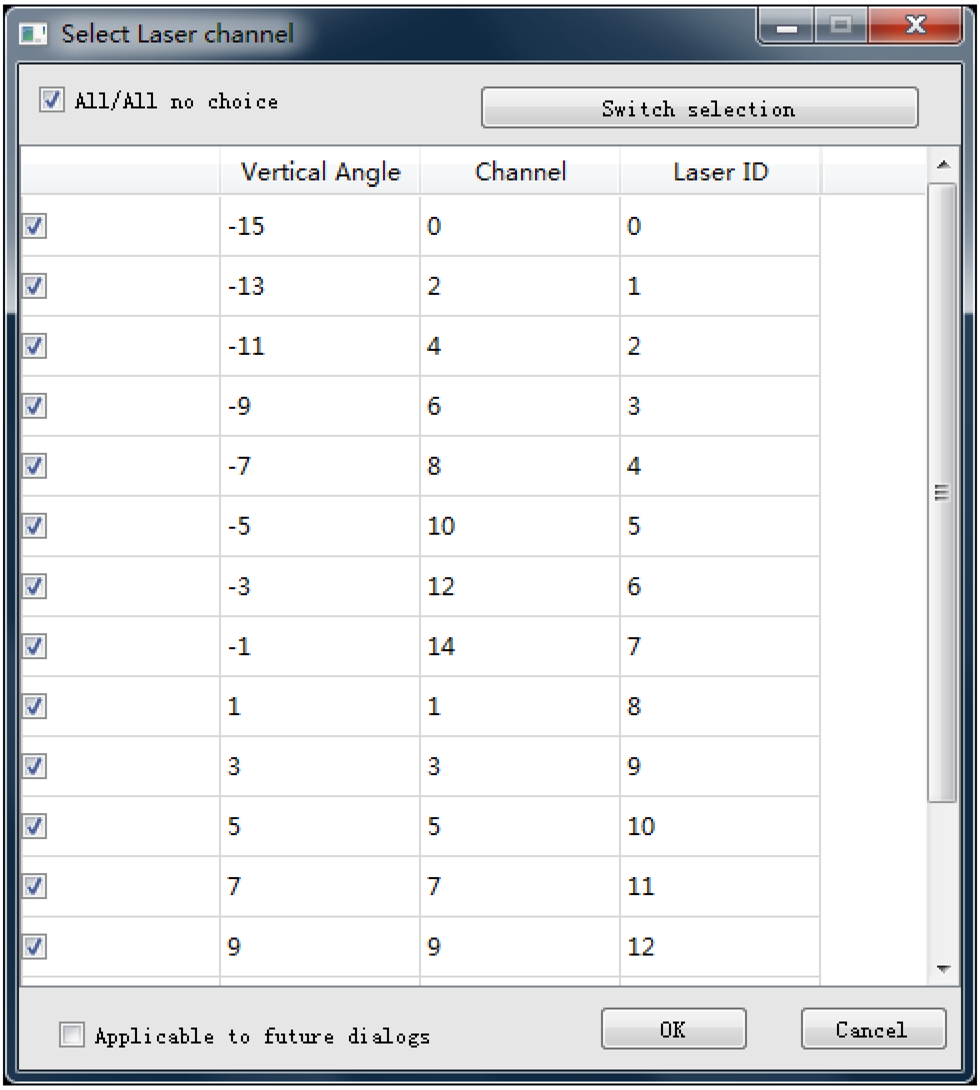
2. Dragging while holding down the right mouse button helps to adjust the perspective of the display interface.

3. Dragging while holding down the mouse wheel helps to pan the display interface; pressing the shift key on the keyboard while clicking the left mouse button can also do.

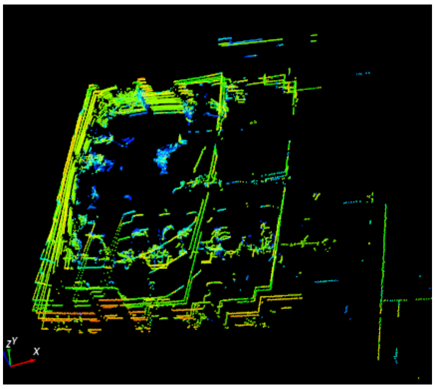
LSC16 Menu



Click  button to control the LiDAR channels signals. click on the left check box to close (open) a channel data, click on the upper left corner of the selection all / all can open (close) all channel data. Click on the lower left corner of the applicable dialog box, you can record the current state of LiDAR harness selection for the next application. The vertical angle in the form table indicates the perpendicular angle of the corresponding channel data, and the channel denotes the data arrangement sequence number of the channel corresponding to the channel, laser id indicates the LiDAR channel number.



As shown in the following figure, the left image shows some of the channel data hidden in the 16 lines, and the right image is the complete data:



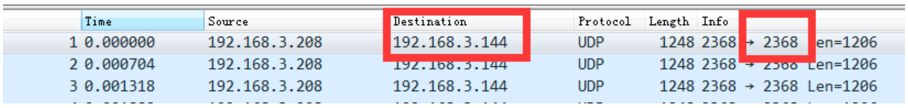
Attention

1. LiDAR setup and use issues:

(1) LeiShen 16-line LiDAR display software cannot be used in two processes (opened twice when it is already running) in the same PC to receive data because the use of PC port is generally exclusive. When one process is bound to a specified port number , other same processes or software using the same port number cannot work normally. For example, if software Veloview uses the same port number, it is impossible to use either of the software in the same PC to receive LiDAR data synchronously, in which case one of the software crashes. Moreover, as the underlying software development using Qt is unable to identify a Chinese path, no Chinese path is recommended in naming a file or a path folder.

When LeiShen 16-line LiDAR display software detects the port is temporarily used, it will prompt for communication network port configuration failure and automatically close the software. Users need to close the process of software that occupies the port, and re-open LeiShen 16-line LiDAR display software for normal operation.

(2) As LeiShen 16-line LiDAR is able to modify the port number through the user configuration so that the LiDAR sends data to the upper computer through the preset destination IP and port, it is necessary to set the IP as the destination IP of the LiDAR when the local notebook or desktop and other device are receiving data. The port bound to program in the local upper computer shall have the set destination port number, as shown below. The packet parameters captured and analyzed by Wireshark are as follows:

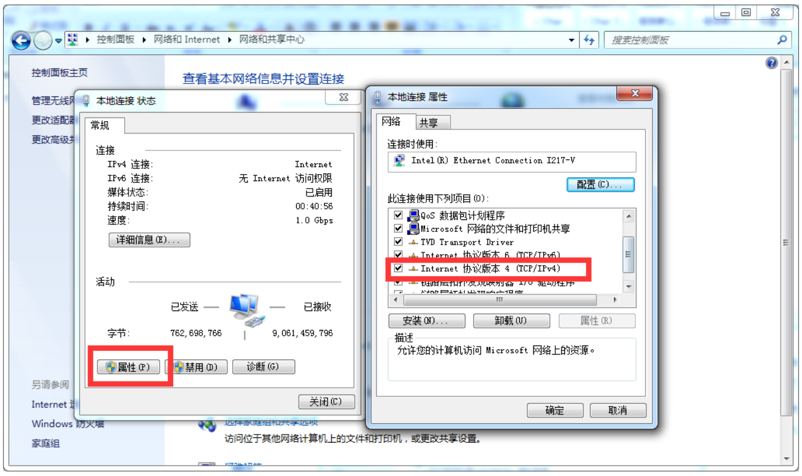


	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.3.208	192.168.3.144	UDP	1248	2368 → 2368 Len=1206
2	0.000704	192.168.3.208	192.168.3.144	UDP	1248	2368 → 2368 Len=1206
3	0.001318	192.168.3.208	192.168.3.144	UDP	1248	2368 → 2368 Len=1206

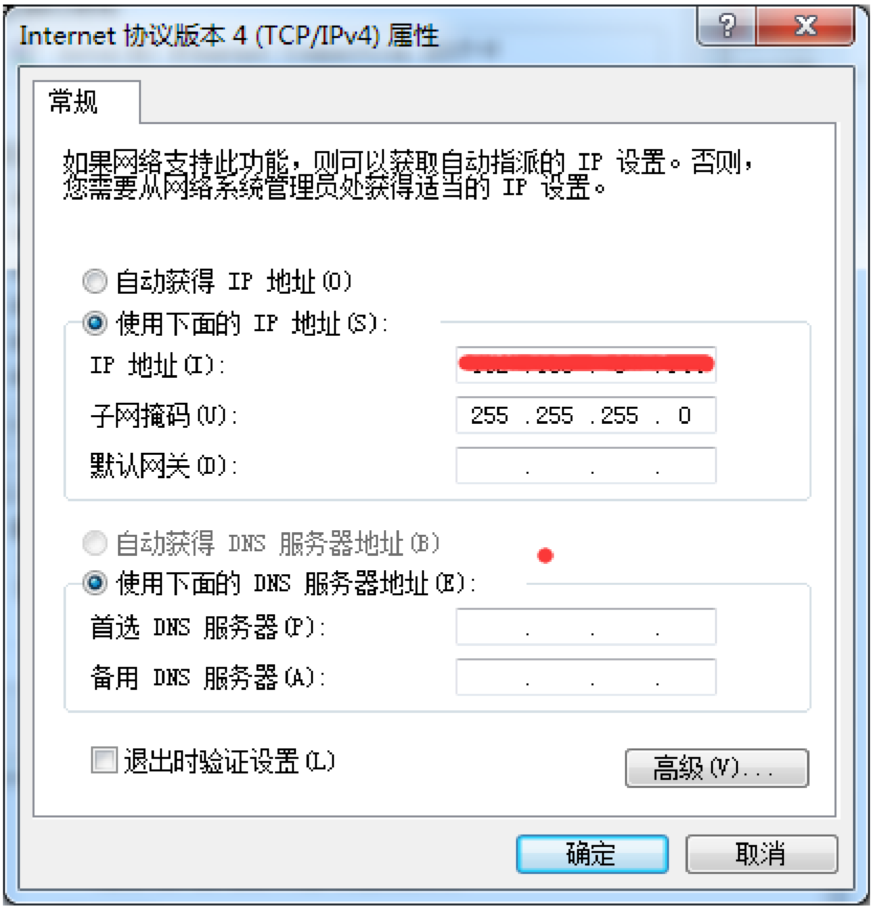
The red boxes indicate the destination IP and port of the LiDAR, respectively.

In Control Panel -> Network and Internet -> Network Share Center, click the Local Area Connection button.

Click Properties in the pop-up status box and click TCP/IP4 Protocol Version in the pop-up Properties box, as shown below.

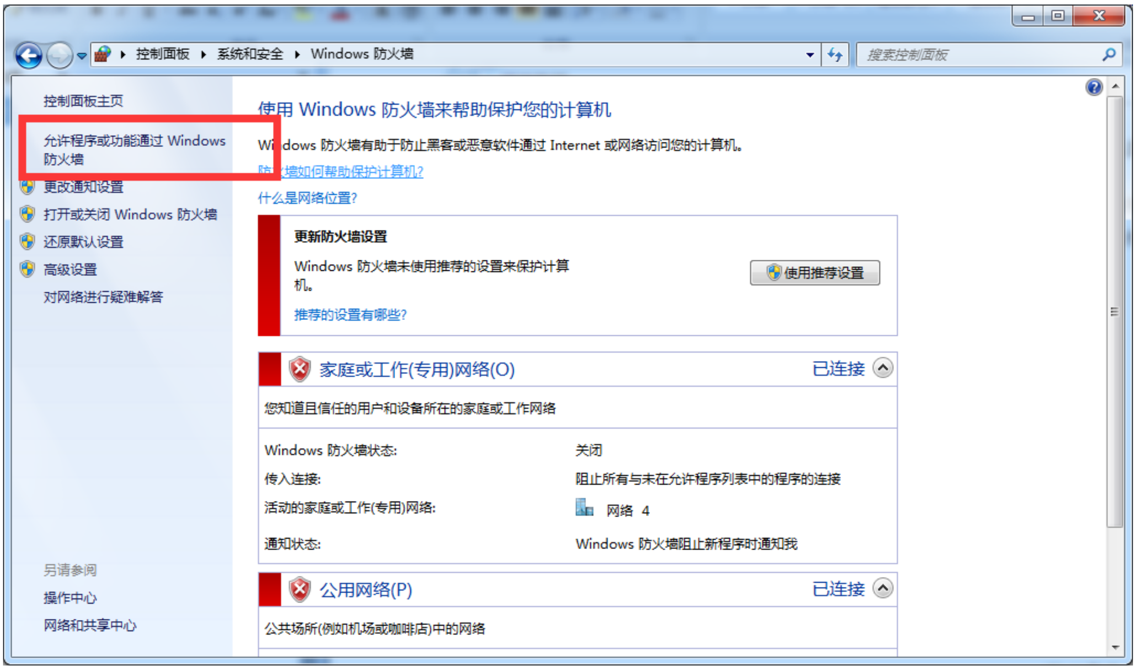


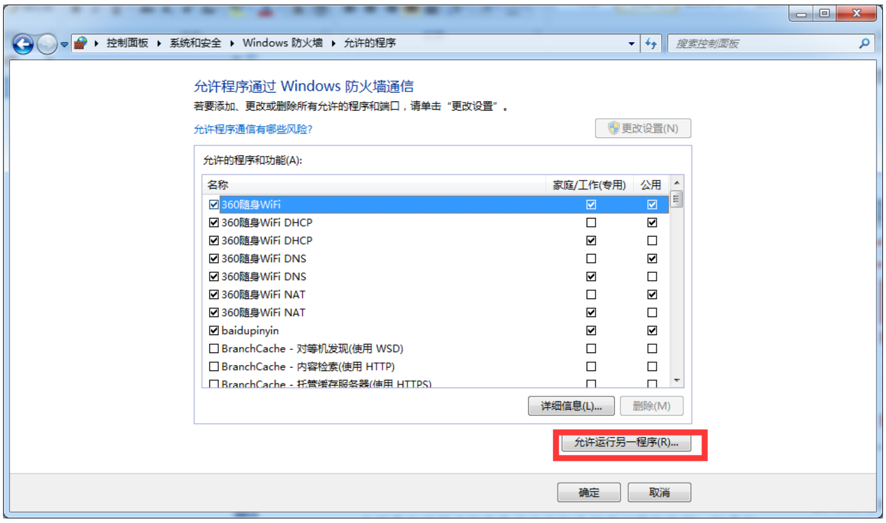
In TCP/IP4 Properties Settings set the IP address to the destination IP of the LiDAR (the default factory IP and port of the LiDAR are shown in the LiDAR communication protocol) and the subnet mask to 255.255.255.0.

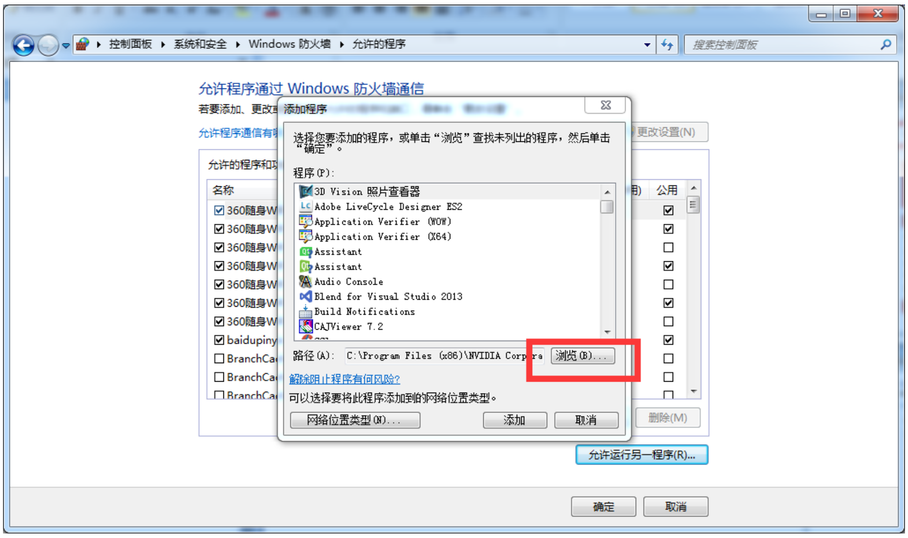


(3) Since LeiShen multi-line LiDAR display system program needs to acquire massive packets via the Internet in a short period of time, it may be prohibited by the network firewall as a malicious program. It is possible that packets are seen to have been sent to the computer using software wireshark to capture packets but are not displayed on the upper computer.

In Control Panel -> System and Security -> Windows Firewall Settings, click Allow a Program or Feature to Pass Through Windows Firewall, as shown below.


控制面板 ▸ 系统和安全 ▸ Windows 防火墙
控制面板主页
允许程序或功能通过 Windows 防火墙
更改通知设置
打开或关闭 Windows 防火墙
还原默认设置
高级设置
对网络进行疑难解答
另请参阅
操作中心
网络和共享中心
使用 Windows 防火墙来帮助保护您的计算机
什么是网络位置?
更新防火墙设置
Windows 防火墙未使用推荐的设置来保护计算机。
推荐的设置有哪些?
使用推荐设置
家庭或工作(专用)网络(O)
已连接
您知道且信任的用户和设备所在的家庭或工作网络
Windows 防火墙状态:
关闭
传入连接:
阻止所有与未在允许程序列表中的程序的连接
活动的家庭或工作(专用)网络:
网络 4
通知状态:
Windows 防火墙阻止新程序时通知我
公用网络(P)
公共场所(例如机场或咖啡店)中的网络


控制面板 ▸ 系统和安全 ▸ Windows 防火墙 ▸ 允许的程序
允许程序通过 Windows 防火墙通信
若要添加、更改或删除所有允许的程序和端口，请单击“更改设置”。
允许程序通信有哪些风险?
更改设置(N)
允许的程序和功能(A):
名称
家庭/工作(专用)
公用
360随身WiFi
360随身WiFi DHCP
360随身WiFi DNS
360随身WiFi NAT
baidupinyin
BranchCache - 对等机发现(使用 WSD)
BranchCache - 内容检索(使用 HTTP)
详细信息(L)...
删除(M)
允许运行另一程序(R)...
确定
取消



Browse to find the software installation path (by default, C:\Program Files (x86)\LeiShenIntelligentSystem\LSVIEW\LSView.exe), and click OK after it is selected to apply the program's network settings. See the following figure for details:

According to the nature of the user's network, check the boxes marked in the red box and click OK to view the data.

2. When LeiShen Intelligent multi-line LiDAR display software is installed in a desktop or laptop with dual GPUs, the default global settings for the computer operating system as use global settings (automatic selection: integrated GPU) have

an effect on the display efficiency of the software. To ensure the use and display efficiency of the software, it is necessary to menually set the computer GPU settings.

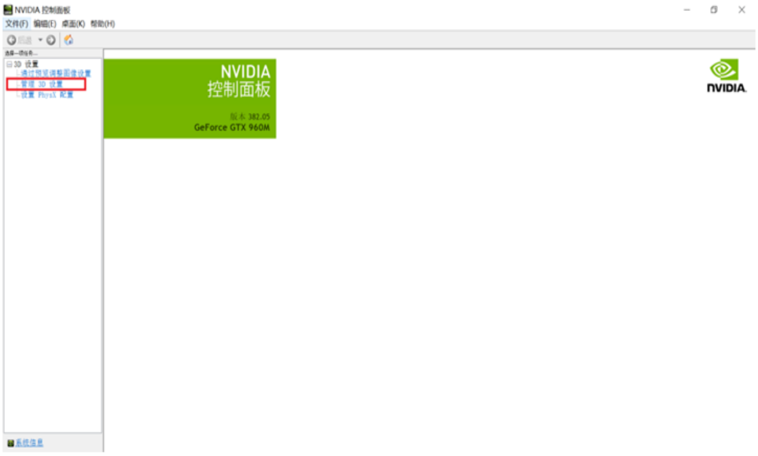
Dual GPUs can be viewed in the computer configuration. As shown below, the computer's display adapter can be seen in My Computer -> Right Button -> Properties -> Device Manager:

So it is necessary to menually adjust the settings by switching the applicable GPU of the software menually to HP discrete GPU. The setting steps are as follows:

1. In case of a notebook with integrated GPU Intel(R)HD Graphics 530 and discrete GPU NVDIA GeForce GTX 960, right-click on the desktop space to pop up the right-click menu and select NVDIA Control Panel.

2. Select Manage 3D Settings button in the pop-up program interface of NVDIA

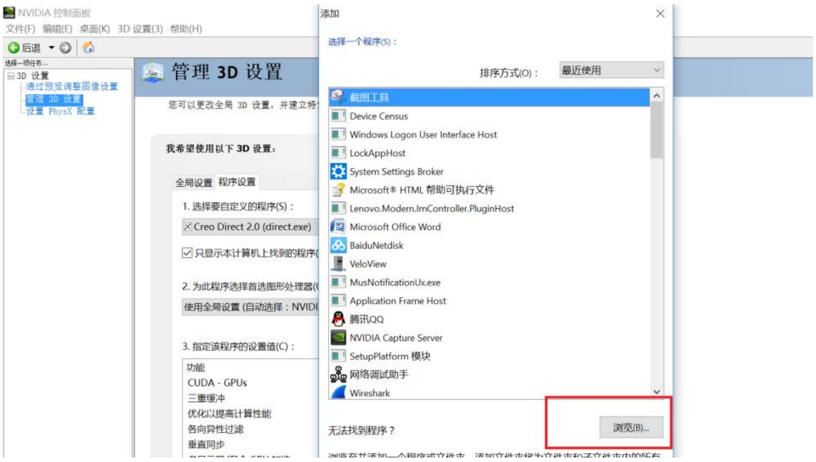
Control Panel, as shown below.



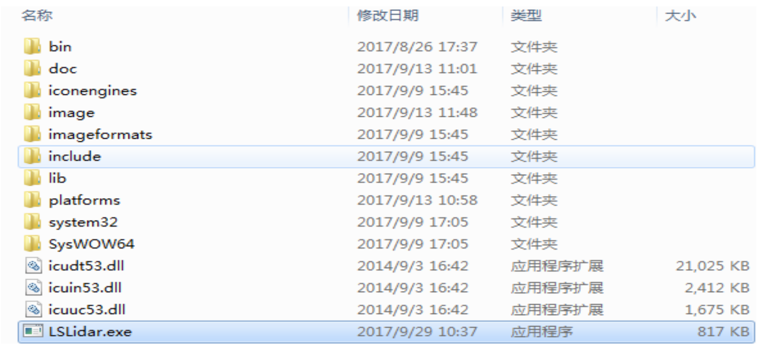
3. Select Program Settings button in Manage 3D Settings interface, as shown below.

4. Click Add button in Manage 3D Settings interface, as shown below.

5. Click Browse button in the pop-up Add interface, as shown below.

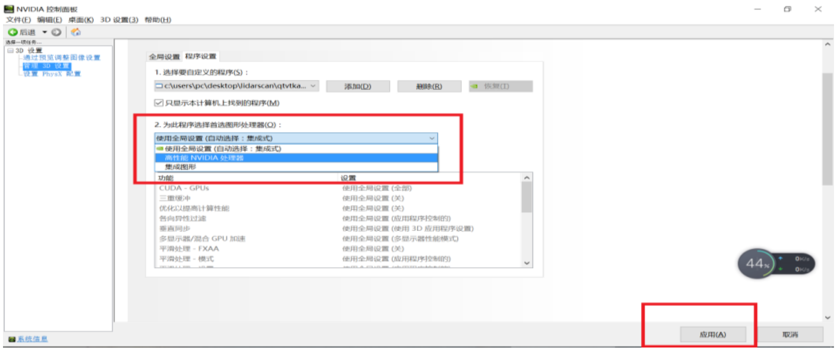


6. Find the application file of the software (.exe file) in the pop-up Browse interface according to its installation path:



7. Click OK to automatically return to NVDIA Control Panel. Select HP NVDIA Processor from the dropdown box under option 2. Select Preferred GPU for This Program and click on the application in the lower right corner. After the computer

application is set, close NVDIA Control Panel to complete settings, as shown below.



Communication Protocol

The LiDAR communicates with the computer via the Ethernet by using the UDP protocol. All protocol packets involving UDP in this document are in fixed length of 1,248byte, 1,206byte for payload, and the rest 42byte for UDP packet overhead. The network parameters of the LiDAR are configurable, using fixed IP and port number as factory default, as shown below.

Table 1 Factory Default Network Configuration

	IP	Port number
LiDAR	192.168.1.200	2368
Computer	192.168.1.102	2368, 2369

The default MAC address of the device is the device's serial number, but the MAC address of the device can be modified. Modifying the MAC address does not entail the change to the device serial number.

When using a connecting device, it is necessary to set the computer IP to the same network segment as the device, for example, IP: 192.168.1.x, and subnet mask: 255.255.255.0. If the device's network configuration information is unknown, wireshark is used for the connecting device to capture the device's ARP packet for analysis after the LiDAR is powered on. For the characteristics of the ARP packet, see the figure below.

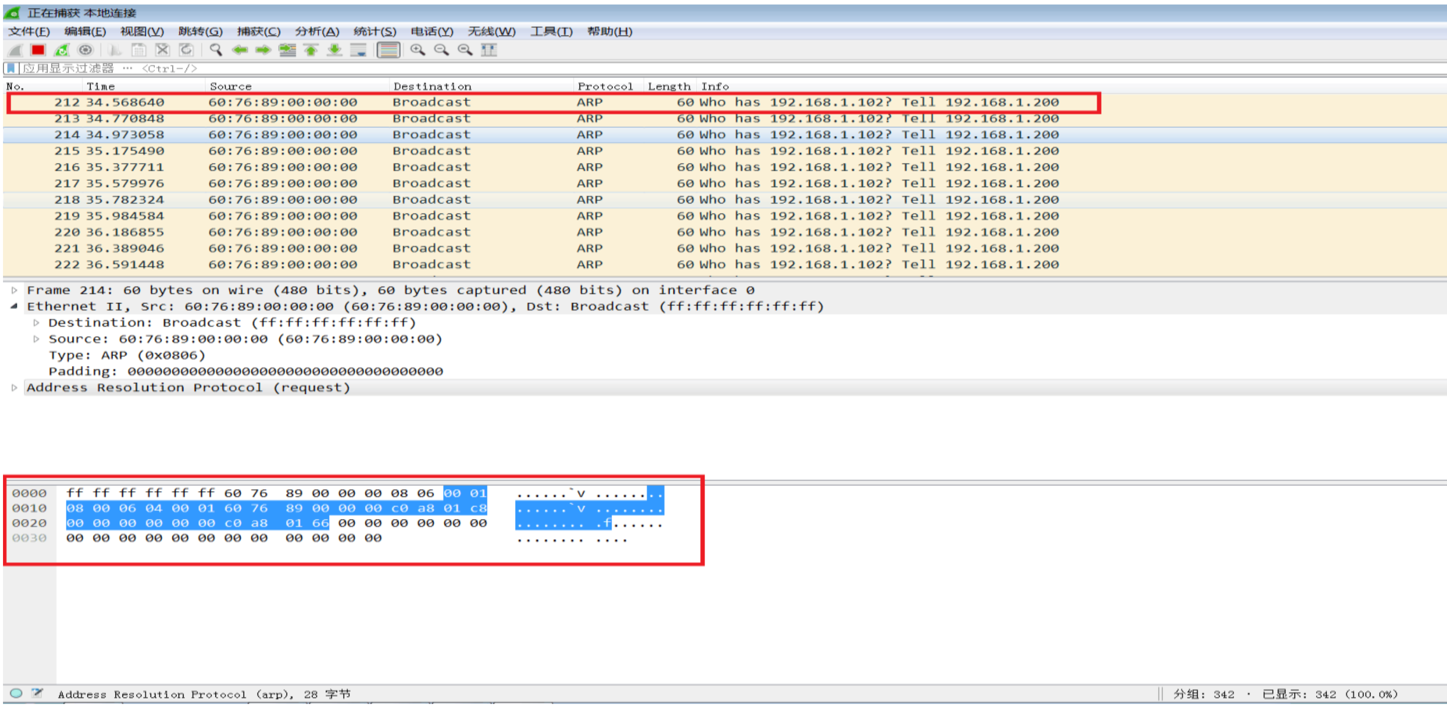


Figure 1 Wireshark Capturing ARP packet

2 bytes	2 bytes	1 byte	1 byte	2 bytes	6 bytes	4 bytes	6 bytes	4 bytes
Hardware type	Protocol type	Hardware address size	Protocol address size	Operating type	Source MAC physical address	Source IP address	Destination MAC address	Destination IP address

Figure 2 ARP Message Content

The communication protocols between the LiDAR and the computer are mainly divided into four categories, as shown in Table 2 below.

- Main Data Stream Output Protocol, by which the information on distance, angle and reflectivity scanned out by the LiDAR is packeted and output to the computer;
- Device Information Output Protocol, by which various configuration information on the current state of the device is monitored;

User Configuration Write Protocol, by which users can re-modify some of the configuration parameters of the device acco

DIFOP

(Protocol/packet) name	Abbreviation	Function	Type	Packet size	Transmission interval
Main data Stream Output Protocol	MSOP	**Outputting scanned data**	UDP	1248bytes	0.6ms
Device Information Output Protocol	DIFOP	**Outputting device information**	UDP	1248bytes	1000ms 或 1.2ms
User Configuration Write Protocol	UCWP	**Inputting user configured device parameters**	UDP	1248bytes	INF

Note: The following sections describe and define the payload (1,248byte) part of the protocol.

Main Data Stream Output Protocol (MSOP)

Main Data Stream Output Protocol, referred to as: MSOP.

I/ I/O type: Device output and computer analysis. All the data in the main data stream are organized in little endian and compatible with Velodyne data format.

MSOP completes the output of the data related to the measurement of 3D field, including such information as the reflectivity of the laser echo, the measured distance value, the angle value and the time stamp, with the size of 1,248 bytes.

A complete MSOP Packet data format structure of the LiDAR includes frame header, sub-frame and frame tail. Each packet has 1,248byte: 42byte for UDP packet overhead, 1,200byte for sub-frame data packet interval (a total of 12 data blocks), 4byte for timestamp, and 2byte for frame tail factory.

MOSP DATA

The 16-chanel LiDAR data supports primary and secondary echoes. When using the primary echo mode,, all primary echo data is transmitted in all 12 data blocks; two emissions from 16 lasers are included in one data block, Sequence information. Each packet contains data for 24 transmit sequences. Each data block returns only one azimuth. See the picture below:

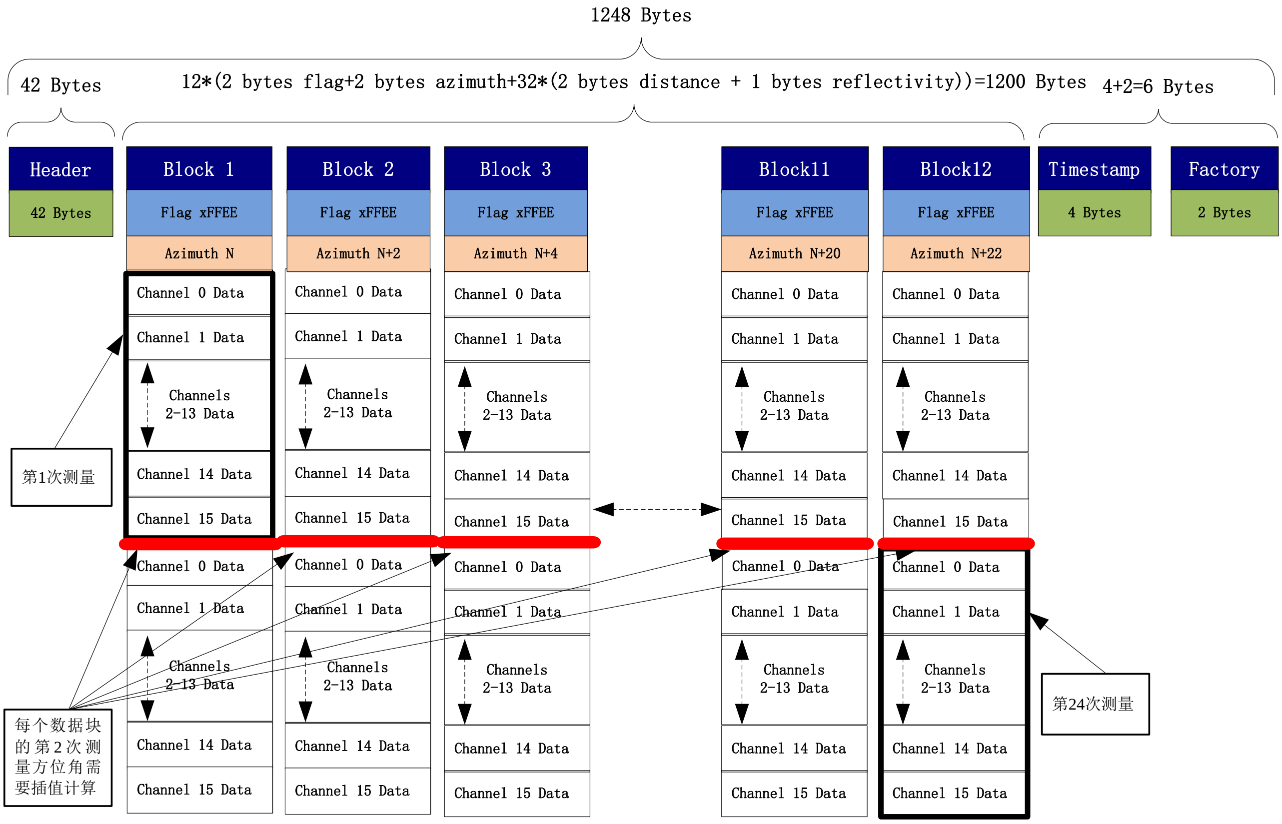
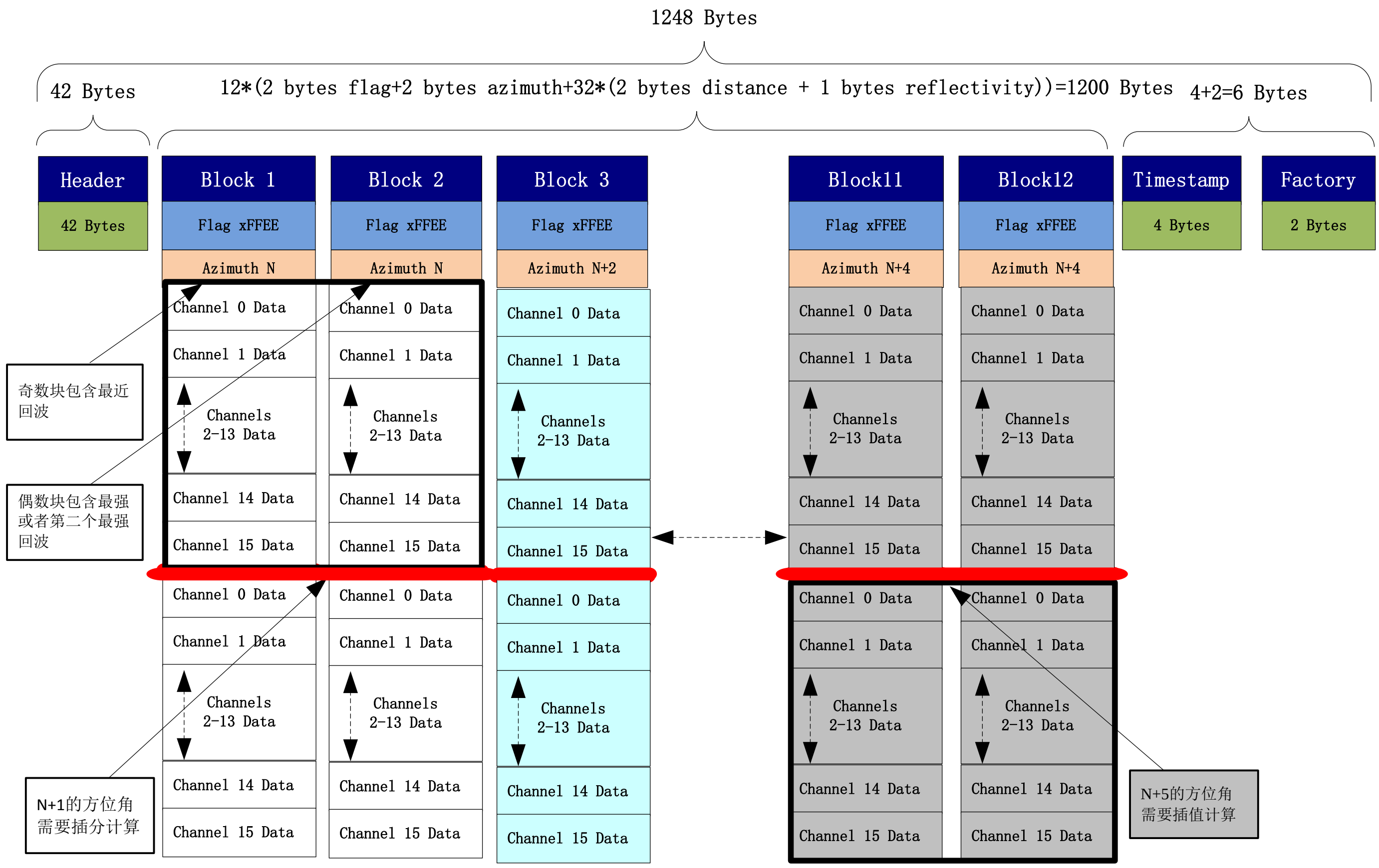


Figure 2 Single echo packet data structure form

- The sensor provides the closest echo and the strongest echo, The sensor transmits a pair of data blocks for each azimuth;

When using double echo mode, two echo data are returned. Information from two transmit sequences of 16 lasers is contained in one data block. The first and second data blocks (DataBlock) are two echo data of the same sequence, and so on. Each packet contains data for 12 transmit sequences. Each data block returns only one azimuth. See the picture below:



1) **Figure 3 Second Echo Packet Data Structure Form**

2) The sensor provides the closest echo and the strongest echo/second strongest echo;

3) The sensor transmits a pair of data blocks for each azimuth;

4) If the closest echo is the strongest one, the second strongest echo is provided as the second echo;

5) For each data block: the first data block contains the closest echo and the

second data block contains the strongest or the second strongest echo;

Frame header

Frame header, UDP packet overhead with a total of 42byte, is used to identify the beginning of the data.

1.1.1 Sub-frame

Sub-frame is a valid data area for data packet with a total of 1,200byte. It consists of 12 data blocks, each 100byte long, representing a complete set of range data. The 100byte space in each data block includes: 2byte flag bit, expressed as 0xffee; 2byte Azimuth, which represents horizontal angle information, each corresponding to 32 channel data and containing two complete sets of 16-channel information.

1.1.1 Angle value definition

For the horizontal angle value of the LiDAR, the angle value of the returned first ranging result among the 16 rounds of laser ranging is selected as the current angle value. The angle value is derived from the angle encoder. The zero-point of the angle encoder is the zero-point of the angle. The resolution of the horizontal angle value is determined based on the motor speed (5Hz, 10Hz, 20Hz) (0.09°, 0.18°, 0.36°). See Figure 3 for the vertical distribution. For horizontal angle distribution, refer to description of single echo angle value and description of second echo angle value by data format.

Table 3 Vertical Angle Distribution of 16 Laser Channels

UDP Package Chanel	Vertical Angle
Chanel 0 Data	-15°
Chanel 1 Data	1°
Chanel 2 Data	-13°
Chanel 3 Data	3°

Chanel 4 Data	-11°
Chanel 5 Data	5°
Chanel 6 Data	-9°
Chanel 7 Data	7°
Chanel 8 Data	-7°
Chanel 9 Data	9°
Chanel 10 Data	-5°
Chanel 11 Data	11°
Chanel 12 Data	-3°
Chanel 13 Data	13°
Chanel 14 Data	-1°
Chanel 15 Data	15°

Table 3 **Vertical Angle Distribution** of C16-xxxC laser channel

UDP Package Chanel	Vertical Angle
Chanel 0 Data	-10°
Chanel 1 Data	0.665°
Chanel 2 Data	-8.665°
Chanel 3 Data	2°
Chanel 4 Data	-7.33°
Chanel 5 Data	3.33°
Chanel 6 Data	-6°
Chanel 7 Data	4.665°
Chanel 8 Data	-4.665°
Chanel 9 Data	6°
Chanel 10 Data	-3.33°
Chanel 11 Data	7.33°
Chanel 12 Data	-2°
Chanel 13 Data	8.665°

Chanel 14 Data	-0.665°
Chanel 15 Data	10°

According to Figure 2, each interval data block contains two sets of measured echo distance data, but each data group has only one angle value, so the data angle needs to be interpolated. The time interval of each ranging is equally spaced, and the angle of rotation is uniform. The interval between each two data blocks is the same, and the two adjacent angle values (Azimuth N and Azimuth (N+1)) are averaged as the horizontal angle value of the second set of ranging data.

When user are analyzing, each angle of 16 channel data measured is interpolated at equal intervals. Dividing the difference between the measured angle in the current group and the one in the previous group by 16 and multiplying the channel number of this point, plus the measured angle value in the previous group produces the angle value of this channel collection point.

For example, in Figure 6, the angle value of the packet is calculated as follows:

Obtain the hexadecimal number for the angle values of the data packet: 0x44, 0x00.

Combine the data into 16bit unsigned integer data, expressed as: 0x0044. Convert it to decimal number: 68. Divide by 100 to produce: 0.68 degree.

Hence, the angle value of this transmitted laser is 0.68 degree.

1.1.1.1 **Channel data definition**

Channel data is 3byte long, with the two high bytes used for storing distance information and the one lower byte used to represent the reflectivity information, as shown below

Channel data n （3 byte）		
2 bytes Distance		1 byteAtten
Distance1[7:0]	Distance2[15:8]	Atten reflectivity information

Note: Distance is 2byte long in cm with resolution of 1cm. The reflectivity is relative reflectivity, and it can reflect the reflectivity performance of the system in the actual measurement environment. The distinction of objects with different materials is made possible through the reflectivity information.

For example, the channel data of a packet is calculated as follows: Obtain the hexadecimal number for the distance values of the data packet: 0x72, 0x06. Combine the data into 16bit unsigned integer data, expressed as: 0x0672. Convert distance values to decimal number: 1650. Divide the distance value by 100 to produce: 16.50 m. Hence, this measured distance is 16.50m.

1.1.2 Frame tail

Tail length 6byte, 4byte Timestamp, 2byte continuous counter bytes, each packet counter is incremented by 1. The user can judge whether network packet loss occurs according to the continuous counting condition.

Table 5 Timestamp Storage Data Format

	Timestamp memory (Timestamp1,243 - 1,246byte position)			
S/N	Byte1	Byte2	Byte3	Byte4
Function	us[31：24]	us [23：16]	us [15：8]	us [7：0]

Table 6 Continuous Counter Bytes

Continuity byte(1247~1248)		
S/N	Byte1	Byte2
Function	Low 8 bytes	High 8 bytes

1. 2 Device Information Output Protocol (DIFOP)

I/O type: device output. The computer reads DIFOP to send Device Serial Number (S/N), Firmware Version Information, Driver Compatibility Information, Network Configuration Information, Calibration Information, Motor Run Configuration, Operating Status and Fault Diagnosis Information to user's Only Output protocol. The user can read DIFOP to interpret the specific information on the various parameters of the current device. **All the data in the device information stream are organized in big endian.**

A complete DIFOP Packet data format structure includes sync frame header, sub-frame and frame tail. Each packet has 1,248byte: including 42byte for UDP packet overhead, 8byte for sync frame header, 1,196byte for Data, and 2byte for frame tail. The basic structure of the data packet is shown in the following table.

Table 7 DIFOP Packet Data Format Structure

Paragraph division	S/N	Information	Offset	Length (byte)
Header	0	DIFOP ID header	0	8
Data	1	Motor speed	8	2
	2	Ethernet	10	26
	3	Time	36	10
	4	LiDAR rotation/silence	46	2
	5	Compatible with Velodyne	48	2
	6	Number of intervals at which device information stream sends packets	50	2
	7	Reserved	52	8
	8	Reserved	60	6
	9	Reserved	66	4
	10	Reserved	70	34
	11	Longitude and latitude	104	22
	12	Reserved	126	1078
Tail	13	Tail	1204	2

Note: The Header (DIFOP ID header) in the table contains 0xA5, 0xFF, 0x00, 0x5A, 0x11, 0x11, 0x55 and 0x55. The first four bytes, 0xA5, 0xFF, 0x00 and 0x5A, can be used as the checking sequences for the packets.

Tail 帧尾内容为 0x0F,0xF0。

Longitude and latitude

Table17 Meaning for Longitude and latitude

Longitude and latitude byte (Total 22bytes)								
S/N	byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7	Byte8
Function	Latitude (byte1 is a discarded byte, 9 bytes from byte2-byte10 represents the							

	latitude value)							
S/N	Byte9	Byte10	Byte11	Byte12	Byte13	Byte14	Byte15	Byte16
Function			Longitude (longitude, from byte11-byte20, a total of 10 bytes for the longitude value)					
S/N	byte17	Byte18	Byte19	Byte20	Byte21	Byte22		
Function	Latitude value				Latitude north and south N/S	Longitude west and east W/E		

Longitude and latitude output protocol, output in ASCII format.

For other fields, see the UCWP Protocol section.

User Configuration Write Protocol (UCWP)

User Configuration Write Protocol, referred to as: UCWPI/O type: the host writes UCWP in to the device Implementation function: users can reconfigure the Ethernet, time, motor and other parameters of the device according to their requirements.

A complete UCWP Packet data format structure includes sync frame header, sub-frame and frame tail. Each packet has 1,248byte: including 2byte for UDP packet overhead, 8byte for sync frame header, 1,238byte for Data, and 2byte for frame tail. **Note that after the user configuration is successfully written, except for the immediate change in the motor speed after the user configuration packet is sent, the rest configuration information takes effect only after the power supply is disconnected. Otherwise, the LiDAR will continue working with the old configuration.** All the configuration data written in to the protocol are organized in big endian.

The protocol followed for the specific contents is shown below:

Table 8 UCWP Packet Data Format Structure

Paragraph division	S/N	Information	Offset	Length (byte)
Header	**0**	**UCWP ID header**	**0**	**8**
	1	**Motor speed**	**8**	**2**
	2	**Ethernet**	**10**	**26**
Data	**3**	**Reserved**	**36**	**10**
	4	**LiDAR rotation/silence**	**46**	**2**
	5	**Reserved**	**48**	**2**

	6	Number of intervals at which device information stream sends packets	50	2
	7	Reserved	52	1152
Tail	8	Tail	1204	2

Note: The Header (UCWP ID header) in the table contains 0xAA, 0x00, 0xFF, 0x11, 0x22, 0x22, 0xAA and 0xAA. The first four bytes, 0xAA, 0x00, 0xFF and 0x11, can be used as the checking sequences for the packets.

The Tail contains 0x0F and 0xF0.

Motor

Table 9 Motor Register Definition

	Motor speed register (2byte)	
S/N	byte1	Byte2
Function	MOTOR	

Description of register:

(1) This register is used to configure motor rotation direction and motor speed;

(2) All the data are stored in big endian;

(3) Configured speed list is as follows:

(Byte1==0x04) && (byte2==0xB0): Speed 1,200rpm, clockwise;

(Byte1==0x02) && (byte2==0x58): Speed 600rpm, clockwise;

(Byte1==0x01) && (byte2==0x2C): Speed 300rpm, clockwise;

Other configured data, motor speed 0.

Ethernet

Table 10 Ethernet Register Definition

<table>
<tr><th colspan="9">Ethernet register (26byte)</th></tr>
<tr><td>S/N</td><td>byte1</td><td>Byte2</td><td>Byte3</td><td>Byte4</td><td>Byte5</td><td>Byte6</td><td>Byte7</td><td>Byte8</td></tr>
<tr><td>Function</td><td colspan="4">IP_SRC</td><td colspan="4">IP_DEST</td></tr>
<tr><td>S/N</td><td>Byte9</td><td>Byte10</td><td>Byte11</td><td>Byte12</td><td>Byte13</td><td>Byte14</td><td>Byte15</td><td>Byte16</td></tr>
<tr><td>Function</td><td colspan="6">MAC_ADDR</td><td colspan="2">port1</td></tr>
<tr><td>S/N</td><td>byte17</td><td>Byte18</td><td>Byte19</td><td>Byte20</td><td>Byte21</td><td>Byte22</td><td>Byte23</td><td>Byte24</td></tr>
<tr><td>Function</td><td colspan="2">Port2</td><td colspan="4">NTP Server IP</td><td colspan="2">Reserved</td></tr>
<tr><td>S/N</td><td>Byte25</td><td>Byte26</td><td colspan="6"></td></tr>
<tr><td>Function</td><td colspan="2">Reserved</td><td colspan="6"></td></tr>
</table>

Description of register:

(1) IP_SRC is source IP address, occupying 4Byte

(2) IP_DEST is destination IP address, occupying 4Byte

(3) MAC_ADDR is MAC address

(4) Port1 - port2 are port number information, occupying 4Byte, port1 is the UDP local port number, and port2 is the UDP destination port number.

(5) The IP address of the NTP server occupies 4 bytes. When the address is set, the LiDAR sends a time request to the NTP server every 4 seconds. After receiving the request, the server sends time information to the LiDAR according to the NTP protocol. The time stamp of the LiDAR is synchronized with the server time.

1.2.1 Time

The defined timestamp is used to record the system time with resolution of 1us. 37 ~ 46byte is used to store timestamp. The storage data format can be found in the time resolution in the table.

Table 11 Timestamp Memory Definition

Timestamp memory										
S/N	Byte21	Byte22	Byte23	Byte24	Byte25	Byte26	Byte27	Byte28	Byte29	Byte30
Function	year	month	day	hour	min	sec	ms		us	

Description of register:

1) year

reg name：set_year								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_year[7:0]: Data 0 - 255 correspond to years 2000 - 2255							

2) month

reg name：set_month								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	Reserved	Reserved	Reserved	Reserved	set_month[3:0]: 1 - 12 month			

3) day

reg name：set_day								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	Reserved	Reserved	Reserved	set_day[4:0]：1~31 day				

4) hour

reg name：set_hour								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	Reserved	Reserved	Reserved	set_hour[4:0]：0~23 hour				

5) min

reg name：set_ min								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	Reserved	Reserved	set_min[5:0]：0~59 min					

6) sec

reg name：set_ sec								
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0

Function	Reserved	Reserved	set_sec[5:0]：0~59 sec

1.2.2 LiDAR rotation/silence

Table 14 LiDAR Rotation/Silence Byte Definition

LiDAR rotation/silence byte (2byte)		
S/N	Byte1	Byte2
Function	Signal flag	

The LiDAR rotates when the transmitted signal is 0x0000, remains silent when the transmitted signal is 0x0001, and substitutes the real-time speed for the distance value when the transmitted signal is 0x0002.

1.2.3 Number of intervals at which device information stream sends packets

Table 15 Definition of Byte of Number of Intervals at Which Device Information Stream Sends Packets

Byte of number of intervals at which device information stream sends packets (2byte)		
S/N	Byte1	Byte2
Function	Set number of intervals	

When the packet sending interval is 0, the LiDAR will send one device information packet for each data packet, so that the user can quickly find the device packet.

When the packet sending interval is not 0, the LiDAR sends 3 device packets every 1 second, and the sending time is the new 1 second just started and the data packet has not been sent yet.

1.2.4 Example

If users want to reset the local IP to 192.168.1.105, the destination IP to 192.168.1.225, the MAC address to 0x001C23174ACC, the local port to 6688, the destination port to 8899 and the LiDAR rotating at the speed of 1,200rpm and compatible with Velodyne, the reconfiguration can be done according to the following table, based on the definitions of UCWP Packet and each register.

Table 18 Configuration Example

Information	Change Content	Configuration	Length (byte)
Header		0xAA,0x00,0xFF,0x11, 0x22,0x22,0xAA,0xAA	8
Rotation speed	1200rpm	0x04B0	2
Local IP (IP_SRC)	192.168.1.200	0xC0A801C8	4
Destination IP (IP_DEST)	192.168.1.102	0xC0A80166	4
Device (MAC_ADDR)	001C23174ACC	0x001C23174ACC	6
Local port (port1)	6688	0x1A20	2
Destination port (port2)	8899	0x22C3	2
NTP Server IP	192.168.1.105	0xC0A80169	4
Reserved	Reserved	0x00	4
Reserved	Reserved	0x00	10
LiDAR rotation/silence	Rotate	0x0000	2
Compatible with Velodyne	Compatible mode	0xABCD	2
Number of intervals at which device information stream sends packets	1	0x0001	2
Others	Reserved	0x00	1152
Tail		0x0F,0xF0	2

When this protocol is used to configure the device, it is not allowed for byte-level or sector-level addressing and writing, and the entire list must be written. **After the list is written, the corresponding function is updated and takes effect as soon as the LiDAR is power-off and restarted.**

Time external synchronization

Four ways to synchronize LiDAR and external system:

I. GPS is locking when synchronizing with GPS timing system. After receiving PPS provided by timing system, LiDAR counts from zero in microsecond. According to UTC, calculate the timing of each data package by adding LiDAR count;

II. When external system provides external synchronizing signal (at the cycle time of 1 second), after receiving external synchronizing rising edge pulse provided by the timing system, LiDAR counts from zero in microsecond. Count value is assigned to main data flow timestamp at byte field for output, when external synchronization rising edge signal arrives, count is cleared to 0;

III. If there is no GPS signal or external synchronizing signal at the start of LiDAR, it runs at the internal clock, and counts from zero in microsecond, count value is assigned to main data flow timestamp at byte field, count to 1 hour and restart from 0;

IV. When the LiDAR and NTP server are connected together, the LiDAR time can be synchronized with the NTP server.

Four-byte timestamp is a 32-bit unsigned integer. The value represents the reception time of the last data of the data package. Four bytes are arranged in small end model. 16-line laser emits every 50us (20K Pulse Repetition Rate) at the interval of 3.125 us. Each data package contains 24 16-line laser data sets, there are 192 laser pulse triggers in total. Refer to 1.1 data package structure modes, 2 data sets store first trip echo and second trip echo generated by 16-line laser, the accumulated time for the whole data package is 0.6ms. It means the data rate is 1666.7 data package/second (1/0.6ms). GPS timestamp feature is used to determine the accurate laser emission time. It allows user to match data point of Leishen C16 LiDAR with pitching, rotating, yawing, latitude, longitude, and elevation of GPS/Inertial measurement system

GPS timing and synchronization

C16 series LiDAR can be synchronized through accurate time provided by GPS. GPS PPS is capable of calculating accurate triggering time of each data point, which supports earth reference and other application. GPS timing module connection with LiDAR and performance conditions are:

- The serial data port output from GPS receiver shall be connected with REC connector of GPS interface on LiDAR adapter;
- The PPS output from GPS shall be connected with PPS connector of GPS interface on LiDAR adapter;
- The ground from GPS hardware output terminal shall be connected with ground connector of GPS interface on LiDAR adapter;
- The default serial baud rate output by GPS data of LiDAR is 9600, 8N1.

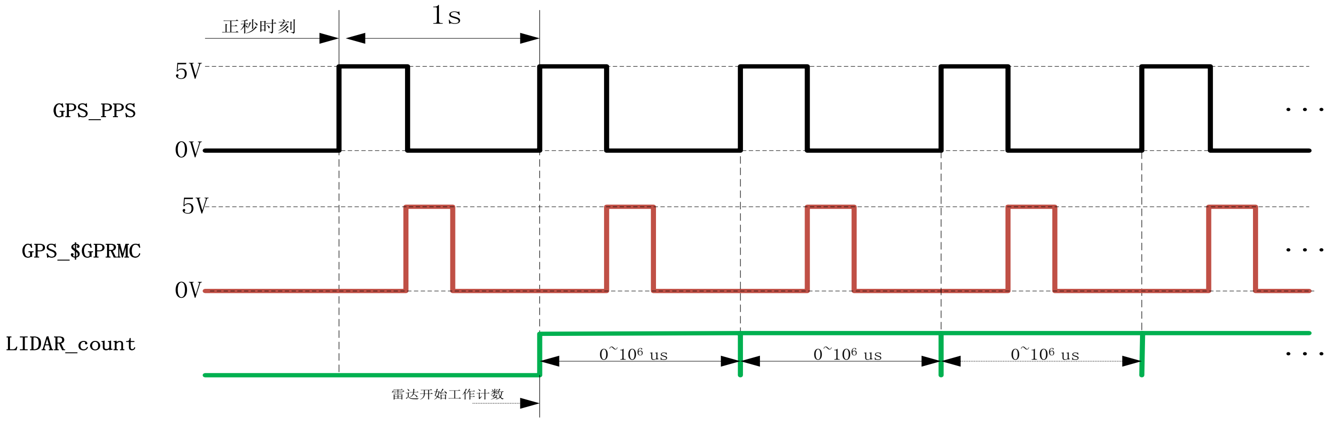


Figure 11: Time Sequence of GPS Timing System Signals

When the time information in the data package $GPRMC provided by GPS is received by LiDAR, assign value to time information numbered 3 in table 7 of DIFOP. Within 1 second, send DIFOP three times (user only need to receive once, as accurate time reference). Data length is 10 bytes, mainly including year, month, day, hour, minute, second, millisecond. $GPRMC data information through GPS is only required to be accurate to second, and based on PPS, when PPS rising edge triggers microprocessor inside LiDAR, count from zero in microsecond, add UTC time of GPS (accurate to second) and MSOP timestamp count value to get accurate time. The timestamp timing in MSOP data package is the last laser pulse data time in MSOP data package. PPS refreshes every 1 second, the count by microprocessor inside LiDAR clears with PPS refresh, cycle count starts from 0 microsecond. After LiDAR receives $GPRMC data information of GPS, it assigns value to time byte field of DIFOP, output three times every second (make sure external receives device information flow). User receives once to set as time reference, see Figure 11 for timing procedures. According to the mode defined by main data flow, one data package contains 12 data blocks and 192 pulse triggers.

Accurate timing calculation of last laser pulse data point (192nd time) of LiDAR one frame data package：

$T_{\text{accurate time of 192nd pulse}} = T_{\text{GPS provided by GPS}} + 1\text{ second} + T_{\text{data package timestamp time}}$

$T_{\text{accurate time of 192nd pulse}}$-------Accurate timing calculation of last laser pulse data point of frame data package;

$T_{\text{UTC provided by GPS}}$-------PPS triggers previous UTC provided by GPS, the timing is given by time byte defined in DIFOP, three times one second, take one as time reference;

$T_{\text{data package timestamp time}}$-------Given by timestamp byte defined in MSOP, it's LiDAR internal time, as shown in Table 19 Timestamp byte field;

Given timestamp time corresponding to the last laser point of LiDAR one frame data package (the time of 192nd laser pulser, as indicated in red box in Table 19), we can calculate the accurate time of other laser points, see Table 19 for details, the formula is shown as follow:

$$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} + \text{TimeOffset}_n - 596.875\text{us (n is between 1-192)}$$

$T_{\text{accurate time of 192nd pulse}}$-------is obtained from the formula above; TimeOffset_n------- is obtained from Table 19;

or it can be expressed as:

$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} +(n-1)\times 3.125\text{ us}-596.875\text{us}$ (n is between 1-192)

As 1-line - 16-line laser pulses emit at the interval of 3.125 us, the formula above applies.

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Table 19 On offset of corresponding time of main data laser point location of one frame data package Unit: us

area	laserID	Header	Data Block1	Data Block2	Data Block3	Data Block4	Data Block5	Data Block6	Data Block7	Data Block8	Data Block9	Data Block10	Data Block11	Data Block12	Timesta
		42 Bytes	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	Flag xFFEE	4 Byte
			Azimuth N	Azimuth N	Azimuth N+2	Azimuth N+2	Azimuth N+4	Azimuth N+4	Azimuth N+6	Azimuth N+6	Azimuth N+8	Azimuth N8	Azimuth N+10	Azimuth N+10	
	0		0	0	100	100	200	200	300	300	400	400	500	500	
	1		3.125	3.125	103.125	103.125	203.125	203.125	303.125	303.125	403.125	403.125	503.125	503.125	
	2		6.25	6.25	106.25	106.25	206.25	206.25	306.25	306.25	406.25	406.25	506.25	506.25	
	3		9.375	9.375	109.375	109.375	209.375	209.375	309.375	309.375	409.375	409.375	509.375	509.375	
	4		12.5	12.5	112.5	112.5	212.5	212.5	312.5	312.5	412.5	412.5	512.5	512.5	
	5		15.625	15.625	115.625	115.625	215.625	215.625	315.625	315.625	415.625	415.625	515.625	515.625	
	6		18.75	18.75	118.75	118.75	218.75	218.75	318.75	318.75	418.75	418.75	518.75	518.75	
First area	7		21.875	21.875	121.875	121.875	221.875	221.875	321.875	321.875	421.875	421.875	521.875	521.875	
	8		25	25	125	125	225	225	325	325	425	425	525	525	
	9		28.125	28.125	128.125	128.125	228.125	228.125	328.125	328.125	428.125	428.125	528.125	528.125	
	10		31.25	31.25	131.25	131.25	231.25	231.25	331.25	331.25	431.25	431.25	531.25	531.25	
	11		34.375	34.375	134.375	134.375	234.375	234.375	334.375	334.375	434.375	434.375	534.375	534.375	
	12		37.5	37.5	137.5	137.5	237.5	237.5	337.5	337.5	437.5	437.5	537.5	537.5	
	13		40.625	40.625	140.625	140.625	240.625	240.625	340.625	340.625	440.625	440.625	540.625	540.625	
	14		43.75	43.75	143.75	143.75	243.75	243.75	343.75	343.75	443.75	443.75	543.75	543.75	
	15		46.875	46.875	146.875	146.875	246.875	246.875	346.875	346.875	446.875	446.875	546.875	546.875	
	0		50	50	150	150	250	250	350	350	450	450	550	550	
	1		53.125	53.125	153.125	153.125	253.125	253.125	353.125	353.125	453.125	453.125	553.125	553.125	
	2		56.25	56.25	156.25	156.25	256.25	256.25	356.25	356.25	456.25	456.25	556.25	556.25	
	3		59.375	59.375	159.375	159.375	259.375	259.375	359.375	359.375	459.375	459.375	559.375	559.375	
	4		62.5	62.5	162.5	162.5	262.5	262.5	362.5	362.5	462.5	462.5	562.5	562.5	
	5		65.625	65.625	165.625	165.625	265.625	265.625	365.625	365.625	465.625	465.625	565.625	565.625	
	6		68.75	68.75	168.75	168.75	268.75	268.75	368.75	368.75	468.75	468.75	568.75	568.75	
Second area	7		71.875	71.875	171.875	171.875	271.875	271.875	371.875	371.875	471.875	471.875	571.875	571.875	
	8		75	75	175	175	275	275	375	375	475	475	575	575	
	9		78.125	78.125	178.125	178.125	278.125	278.125	378.125	378.125	478.125	478.125	578.125	578.125	
	10		81.25	81.25	181.25	181.25	281.25	281.25	381.25	381.25	481.25	481.25	581.25	581.25	
	11		84.375	84.375	184.375	184.375	284.375	284.375	384.375	384.375	484.375	484.375	584.375	584.375	
	12		87.5	87.5	187.5	187.5	287.5	287.5	387.5	387.5	487.5	487.5	587.5	587.5	
	13		90.625	90.625	190.625	190.625	290.625	290.625	390.625	390.625	490.625	490.625	590.625	590.625	
	14		93.75	93.75	193.75	193.75	293.75	293.75	393.75	393.75	493.75	493.75	593.75	593.75	
	15		96.875	96.875	196.875	196.875	296.875	296.875	396.875	396.875	496.875	496.875	596.875	596.875	

Synchronization of external synchronization pulse

C16 series LiDAR can synchronize with external system by connecting external synchronizing signal without GPS timing module. External synchronizing signal provides benchmark reference for calculating accurate triggering time of each data point. When inside of LiDAR is triggered and detects the rising edge of external synchronizing signal, it will count from zero in microsecond, cycling through the next signal, the LiDAR count is assigned to Timestamp of MSOP, and output with main data flow. External synchronizing signal hardware connection still adopts GPS external port on adapter. The conditions of connection of external synchronizing signal and LiDAR hardware are:

- The REC connector of GPS interface on LiDAR adapter is not connected;
- The PPS connector of GPS interface on LiDAR adapter is connected with external synchronization clock signal level signal (level signal is between 3.3V-5V);
- The ground connector of GPS interface on LiDAR adapter is connected with the ground of external synchronization;

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- External synchronizing signal is sent every one second, the inside of LiDAR responses on rising edge, duty ratio is recommended to be 50% (check on rising edge to adjust duty ratio).

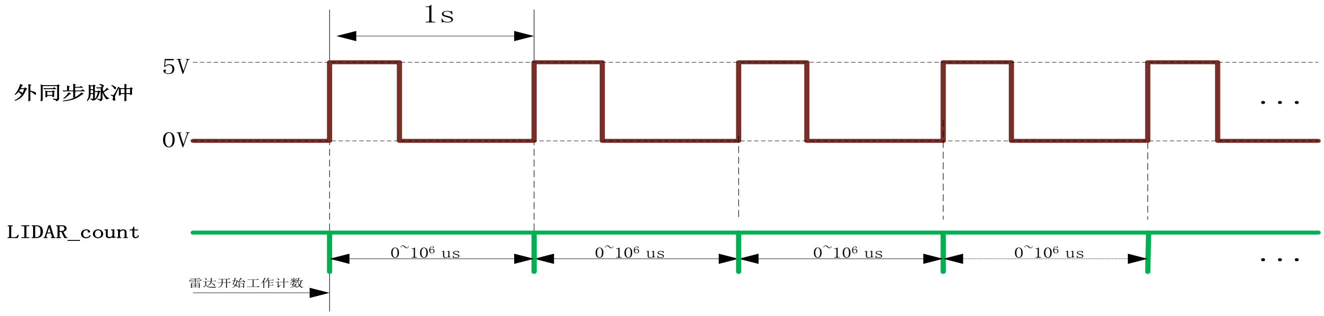

Figure 12: Time Sequence of External Synchronization Pulse Signals

Accurate timing calculation of last laser pulse data point (192nd time) of LiDAR one frame data package

$T_{\text{accurate time of 192nd pulse}} = T_{\text{external synchronization time reference}} + T_{\text{data package timestamp time}}$

$T_{\text{accurate time of 192nd pulse}}$-------Accurate timing calculation of last laser pulse data point of frame data package;

$T_{\text{external synchronization time reference}}$-------External system time reference;

$T_{\text{data package timestamp time}}$-------Given by timestamp byte defined in MSOP, it's LiDAR internal time, as shown in Table 19 Timestamp byte field;

Given the timestamp of last laser point of LiDAR one frame data package (the time of 192nd laser pulse, indicated in red box in Table 19), it's able to calculate the accurate time of other laser point according to the table below. See Table 19 for details. T accurate time of 192nd pulse is obtained through the formula above, TimeOffset n can be obtained from Table 19, the formula is as follow:

$$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} + \text{TimeOffset}_n - 596.875\text{us (n is between 1-192)}$$

or it can be expressed as:

$$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} + (n-1)\times 3.125\text{ us} - 596.875\text{us (n is between 1-192)}$$

As 1-line - 16-line laser pulses emit at the interval of 3.125 us, the formula above applies.

Time account inside LiDAR

If there is no GPS signal or external synchronizing signal connection for C16 series LiDAR, it counts with the internal clock, and counts from zero in microsecond, count to 1 hour (360×10^6 us) and restart from zero. The count is assigned to Timestamp of MSOP, and output with main data flow.

Timestamp of MSOP is the time of last laser emission of this data package, the accurate time of last laser pulse data point (192nd) is represented as $T_{\text{accurate time of 192nd pulse}} = T_{\text{data package timestamp time}}$.

Given the timestamp of last laser point of LiDAR one frame data package (the time of 192nd laser pulse, indicated in red box in Table 19), it's able to calculate the accurate time of other laser point according to the table below. See Table 19 for details. TimeOffset n can be obtained from Table 19, the formula is as follow:

$$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} + \text{TimeOffset}_n - 596.875\text{us (n is between 1-192)}$$

or it can be expressed as:

$$T_{\text{accurate time of n pulse}}=T_{\text{accurate time of 192nd pulse}} + (n-1)\times 3.125\text{ us} - 596.875\text{us (n is between 1-192)}$$

As 1-line - 16-line laser pulses emit at the interval of 3.125 us, the formula above applies.

NTP time synchronization

When the radar is connected to the NTP server, the radar time can be synchronized with the NTP server. The radar periodically acquires the NTP server time. After the server time is obtained, the local time is updated and counted based on the time. The count amount is assigned in real time to the timestamp byte (Timestamp) in the main data stream (MSOP), which is output with the main data stream.

The timestamp byte (Timestamp) in the main data stream (MSOP) is the time of the last laser emission data point of the data packet. The exact time of the last laser pulse data point (192nd time) is expressed as $T_{\text{192th pulse accurate time}} = T_{\text{Packet timestamp time}}$;

It is known that the last laser spot of the radar one-frame data packet (the 192th laser pulse time, the red frame marked position in Table 19) corresponds to the time stamping time, and the accurate time of other laser points can be calculated according to the following table. It can be seen that TimeOffset n can be obtained by looking up the table in Table 19. The calculation formula is as follows:

$T_{\text{n pulse accurate time}} = T_{\text{192th pulse accurate time}} + TimeOffset_n - 596.875us$ （n is from 1 to 192）

Or the formula can also be expressed as:

$T_{\text{n pulse accurate time}} = T_{\text{192th pulse accurate time}} +$ （n-1）*3.125us - 596.875us （n is from 1 to 192）

Since the continuous emission interval of 1~16 laser pulse cycles is 3.125us, it can be converted according to the above formula.

PPS azimuth synchronization

When the LiDAR is synchronized in the PPS seconds pulse time, the laser can simultaneously synchronize the horizontal angle of the radar. The default horizontal angle is 0 degrees. The user can set the required horizontal angle of the PPS synchronization. When multiple radar installations are synchronized, different radars have different scans. The requirement for the starting horizontal angle.

When the PPS input of GPS or external clock synchronization signal is valid, the horizontal angle is automatically synchronized, and the synchronization accuracy is ±5°. When using NTP or PTP network time synchronization, the radar first resolves the second pulse time synchronization signal and then horizontally synchronized, due to different application scenarios. There is an uncertain delay in the network. At this time, the horizontal angle synchronization can only achieve coarse synchronization. The specific accuracy is subject to the actual measurement scenario.

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