镭神智能
LeiShen Intelligent System

Operation Instruction of C16 Series Multi-Channel Hybrid Solid-State LiDAR

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LiDAR Parameters

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 $\times (t_2 - t_1)/2$

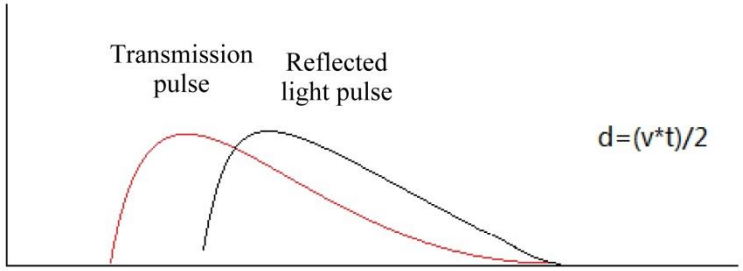


Figure 1 Principle of Measurement

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).

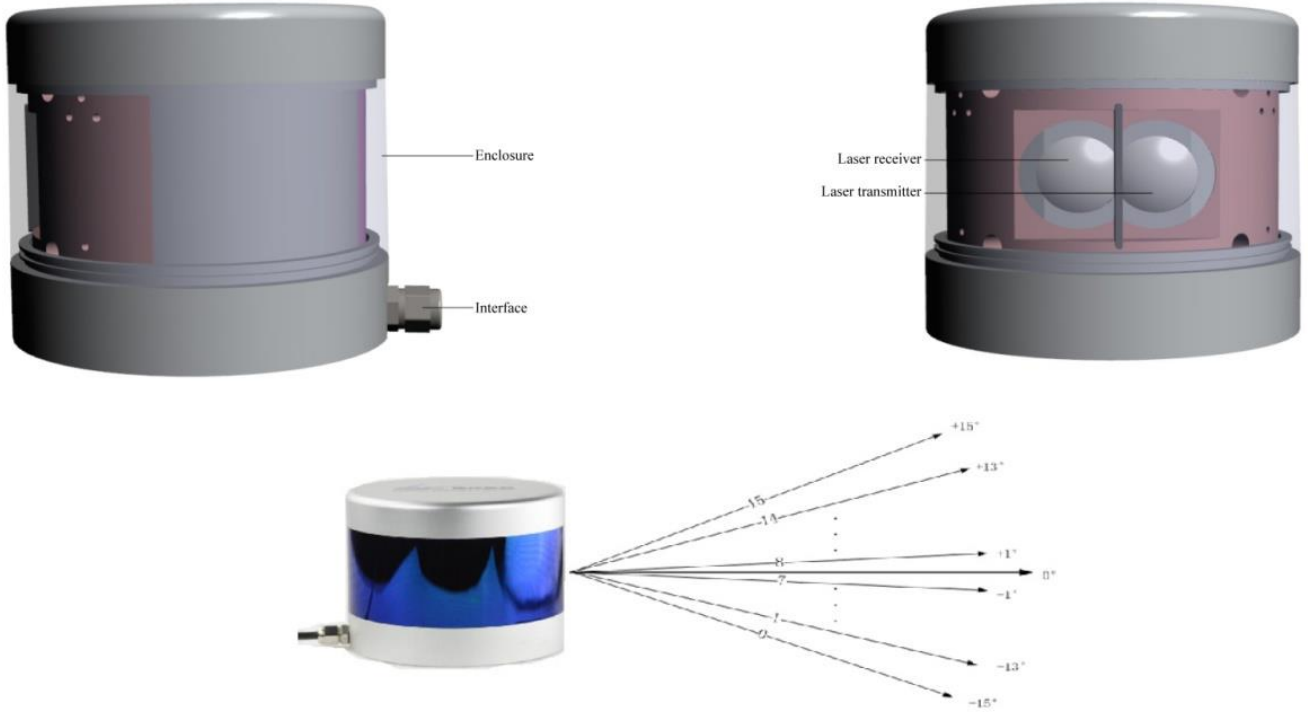


Figure 2 Exterior Structure Diagram

Specifications of LeiShen Intelligent 16-Channel Lidar

Model		**C16-xxxA**		
Ranging mode		**Pulse type**		
Laser band		**905nm**		
Laser class		**Class 1 (eye-safe)**		
Laser channel		**16-channel**		
Signal transmission mode		**Wireless power and signal transmission**		
Maximum range		**50 - 70 m (Reflectivity of 70%)**	**120 m (Reflectivity of 70%)**	**150 m (Reflectivity of 70%)**
Minimum range		**0.5 m**	**0.5 m**	**0.5 m**
Range accuracy		**±10cm**	**±3cm**	**±3cm**
Data acquisition speed		**Max 320,000 pts/sec**	**Max 320,000 pts/sec**	**Max 320,000 pts/sec**
Viewing Angle	Vertical	**±15 °**	**±15 °**	**±15 °**

	Horizontal	**360 °**	**360 °**	**360 °**
Angle Resolution	Vertical	**2 °**	**2 °**	**2 °**
	Horizontal	**5Hz: 0.09 º 10Hz: 0.18 º 20Hz: 0.36 º**	**5Hz: 0.09 º 10Hz: 0.18 º 20Hz: 0.36 º**	**5Hz: 0.09 º 10Hz: 0.18 º 20Hz: 0.36 º**
Sweep Speed	Vertical	**16-channel vertical solid connection**		
	Horizontal	**5Hz, 10Hz, 20Hz (optional)**		
Control module		**Upper computer software settings**		
Communication interface		**Ethernet external communication**		
Supply scope		**+9V～+48VDC**		
Operating temperature		**-10℃～+60℃**		
Storage temperature		**-20℃～+85℃**		

Light conditions	**Operating under either strong sunlight or in darkness**
Temperature	**Non-condensing**
Impact	**500 m/sec ², for 11 ms**
Vibration	**5Hz～2000Hz,3G rms**
IP Grade	**Up to IP67 (customized on demand)**
Dimension	**Φ120mm*110mm**
Weight	**About 1,500g**

※Structure size

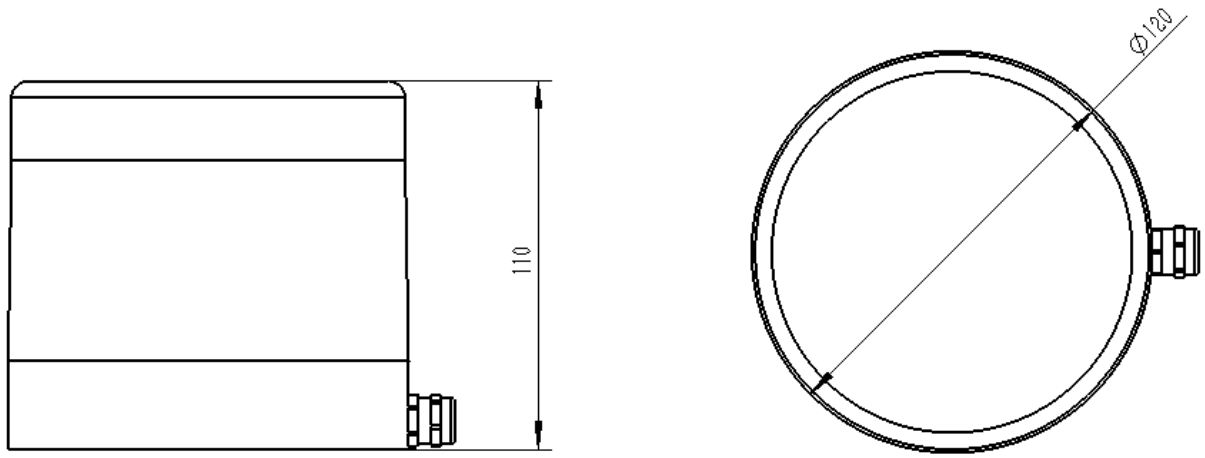


Figure 3 16-line Lidar Structure Size Diagram

Interface description

Electrical interface

1.1 Device power supply

Device power supply input range: 9VDC - 48VDC, use of input voltage 12VDC recommended.

2.2 Definition of device lead output interface

C16 series multi-line lidar body leads cable (10-core shielded wire with serial number shown as below) from the side at the lower side.

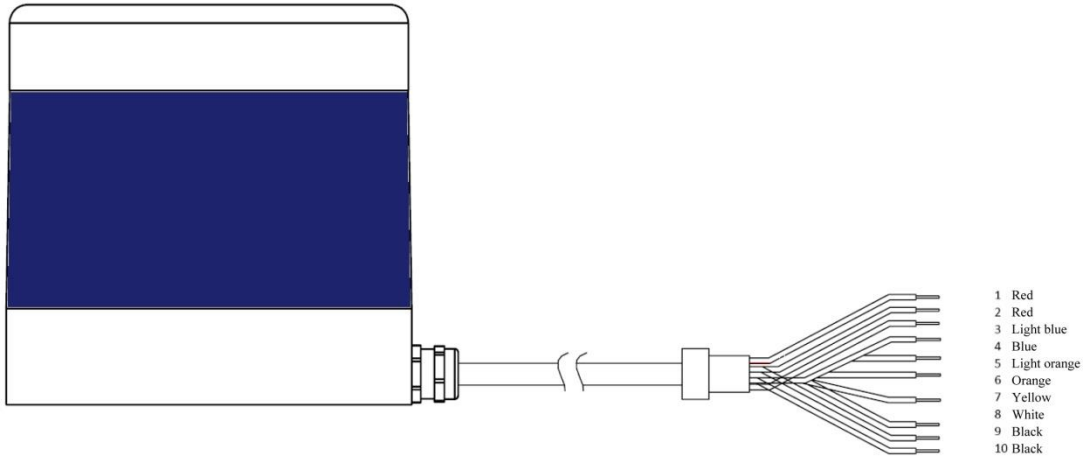


Figure 1 LiDAR Outgoing 10-core Cable

10-core cable is defined as follows:

S/N	Cable color and specifications	Definition	Description of definitions	Quantity
1	Red (22AWG)	VCC	Positive power supply	1
2	Red (22AWG)	VCC	Positive power supply	1
3	Light blue (26AWG)	TD_N	Positive Ethernet transmitter differential	1
4	Blue (26AWG)	TD_P	Negative Ethernet transmitter differential	1

5	**Light orange (26AWG)**	**RD_N**	**Positive Ethernet receiver differential**	**1**
6	**Orange (26AWG)**	**RD_P**	**Negative Ethernet receiver differential**	**1**
7	**Yellow (26AWG)**	**GPS_PPS**	**GPS timing receiving**	**1**
8	**White (26AWG)**	**GPS_REC**	**GPS timing and synchronization clock**	**1**
9	**Black (22AWG)**	**GND**	**Negative power supply (GND)**	**1**
10	**Black (22AWG)**	**GND**	**Negative power supply (GND)**	**1**

Users can use the C16 series multi-line lidar to insert the 10-core terminal cable into the adapter box by just opening the adapter box cover and inserting the 10-core cable into the marked position, as indicated below.

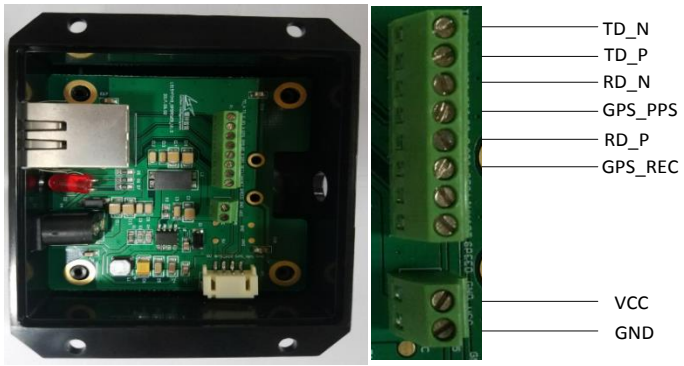
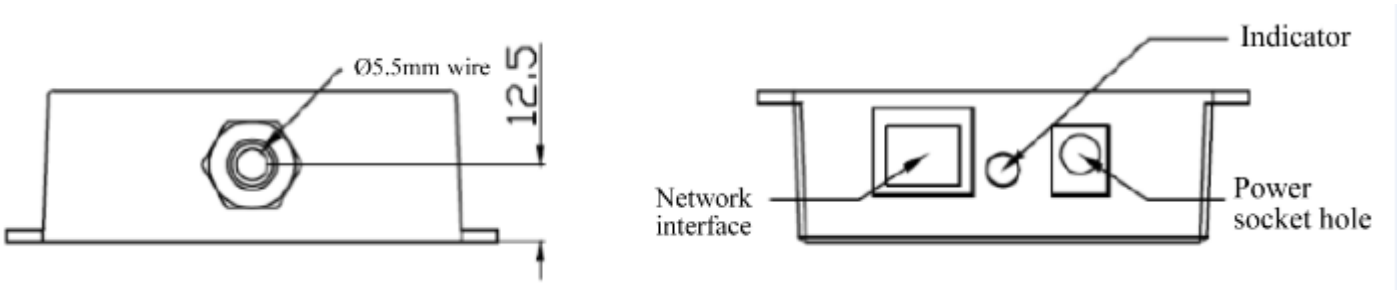


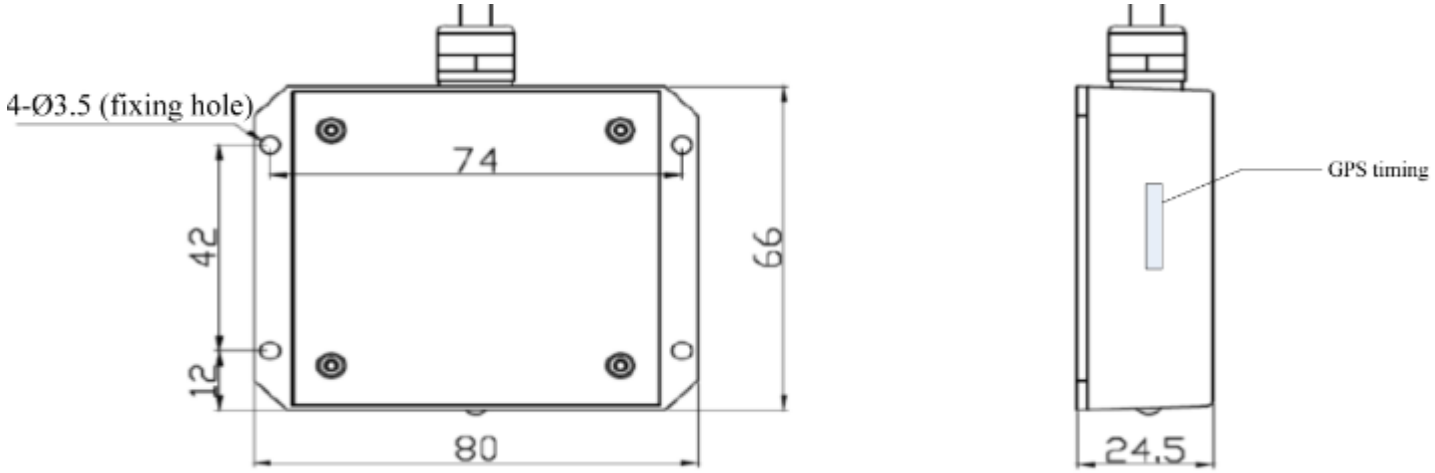
Figure 2 Terminal Block Definition

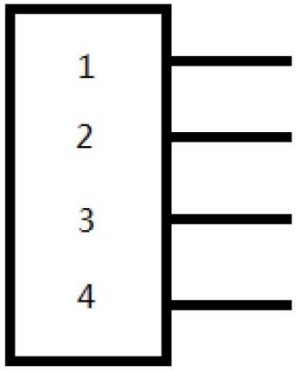
By default, C16 series multi-line lidar is provided with an adapter box. The line from the lidar to the adapter box is 1.5 meter, as shown below.

Figure 3 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 GPS timing interface.







Pin	Description
1	GNP
2	GPS_PPS
3	GPS_REC
4	+5V input

GPS interface

Figure 4 Terminal Block Definition

Mechanical interface

During installation, the device is located by five locating holes. **Data line interface is positioned at the specified horizontal angle of 180 degrees**. The LiDAR is rotated clockwise.

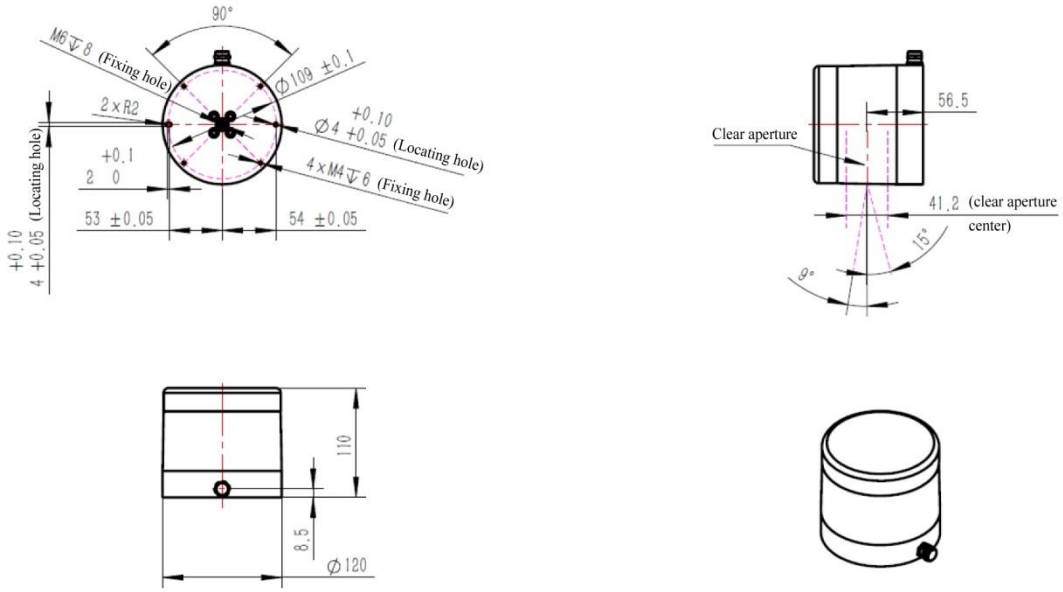


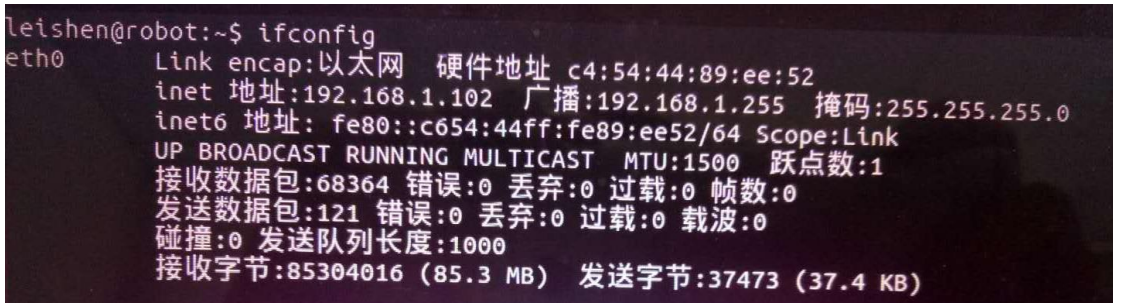
Figure 5 Mechanical Interface Diagram

Usage Guide under ROS System

Hardware connection and testing

1. Connect the Ethernet interface and power cord.

2. Set the computer wired connection IP according to the target IP set by the LiDAR. (ifconfig can be used to command to check whether the wired ip is set successfully,As shown below ip is 192.168.1.102).

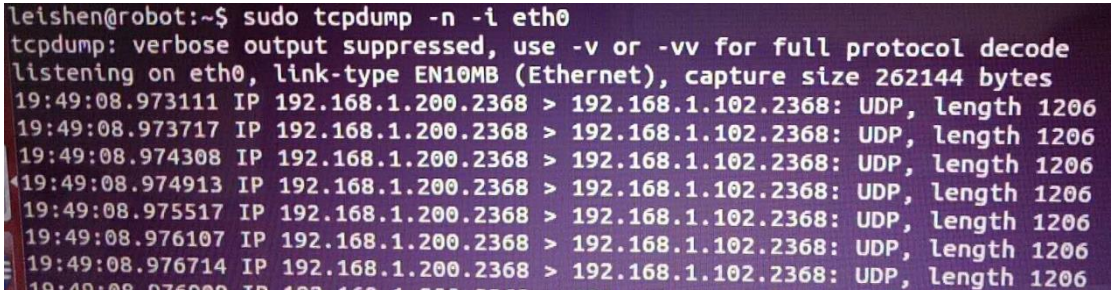


Notes：LiDAR Default IP：192.168.1.102. The computer should be configured according to the destination IP modified by the actual configuration of the LiDAR.

1. Turn on the Lidar, and check the wired connection icon of you computer and make sure that the computer is properly connected.

2. Open terminal: ping Lidar IP to see if the hardware is connected successfully, if you receive a response, you’re connected, otherwise check the hardware connection

3. Use: sudotcpdump-n–ieth0 (eth0 indicates the name of wired network device, refer to ifconfig wired connection for the name of device) to check for Lidar data transfer **(as shown in the figure, 1206 bytes of data is sent to the target, it means the Lidar data transfer is successful)**



Remark: After setting IP for the first time, restart Lidar.

Software operation example

1. Establish work space, build a compiling environment
mkdir -p ~/leishen_ws/src
cd ~/leishen_ws

> **Remark:**
>
> You can name the work space as you like, for example there is leishen_ws, no limitation.

2. Download Lidar driver and dependent package

> **Remark:**
>
> Driver and dependent package are available at the website or customer service of our company. Copy lslidar_c16_V1.01.180118.tar to the newly establish work space turtlerot_ws/src, then decompress it with command tar–xvflslidar_c16_V1.01.180118.tar

3. Compiling and packing

cd ~/leishen_ws

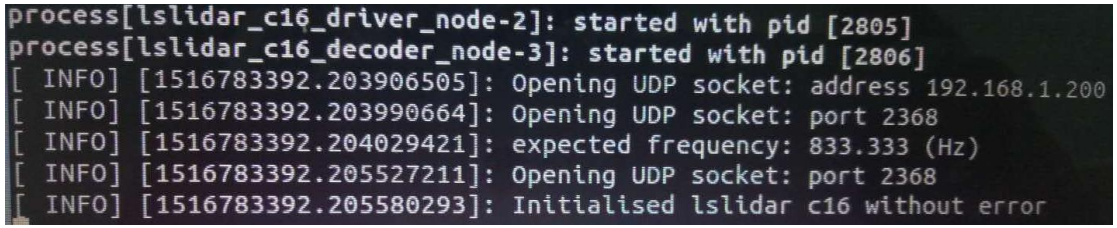
catkin_make

4. Running program

source ~/leishen_ws /devel/setup.bash

roslaunch lslidar_c16_decoder lslidar_c16.launch --screen

Remark: If the destination port and rotation speed are changed, open lslidar_n301n.launch to alter the configuration accordingly. The default port is 2368, rotation speed is 10HZ, i.e. point_num is 2000.



Remark: If timeout is displayed, it means driver receives no data, please check hardware connection.

Open a new terminal and execute the following commands:

rosrun rviz rviz

> **Remark:**
>
> It step 1, 2, and 3 are completed, you only need to start from step 4 when you open Displays window next time.

5. Display the data measured by Lidar

In the pop-up Displays window, change the value of “FixedFrame” to laser and click add button, click PointCloud2 under Bytopic to add multi-line point cloud nodes.

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.

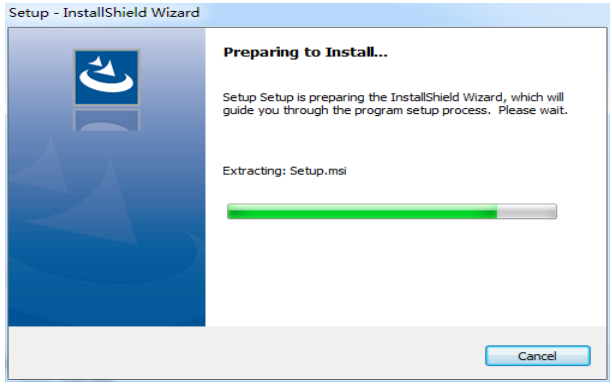
Software installation

1. Installation environment

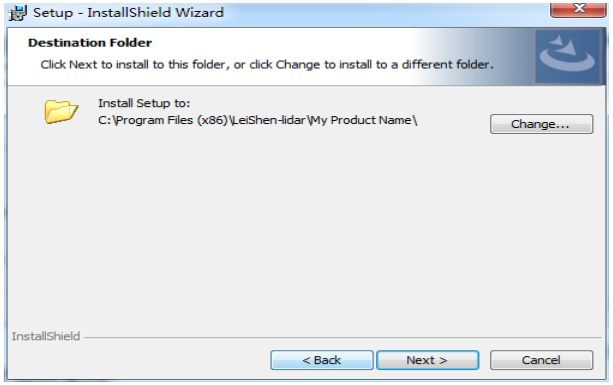
This software is currently only applicable in the Windows x64 system operating platform. The configuration requirements for the computer installing the software are: CPU: Intel (R) Core (TM) i5 or above, GPU: NVDIA GeForce GTX750 or above (most desirable), or it may influence the software display effect. After Leishen multi-line software is installed, **WinPcap third-party library that comes with installation document shall also be installed**.

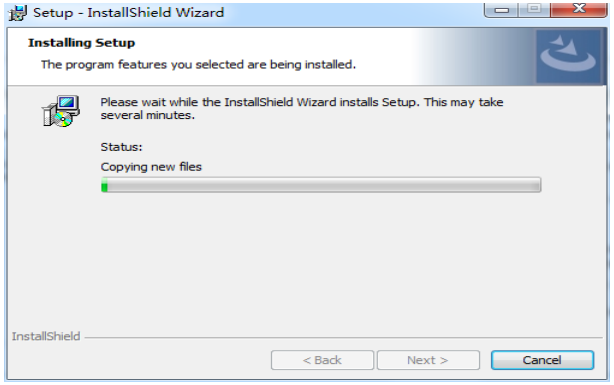
2. Insert the CD-ROM for software installation included with the lidar into the CD/DVD drive. Open the CD-ROM and double-click 

to install the file and the installation interface will pop up.

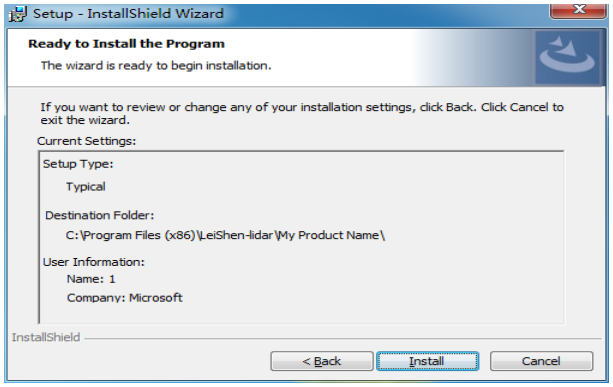


3. Click next to enter the installation path selection interface.





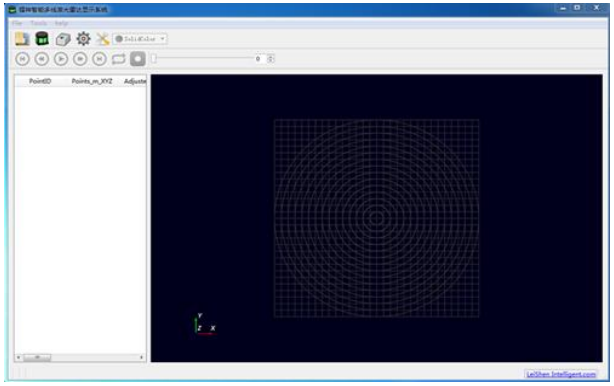
4. After customizing the installation path (do not use a path in Chinese), click next to enter the installation interface and click the install button. Wait until the installation is completed.



Introduction and use of related functions

- Operation of multi-line lidar display system of LeiShen Intelligent

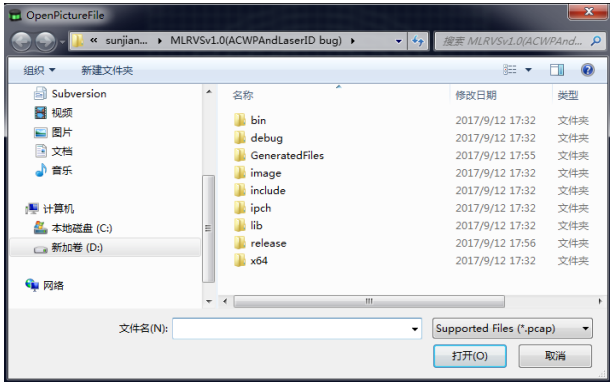
Double-click the shortcut icon on the desktop:  The initial interface is shown below:



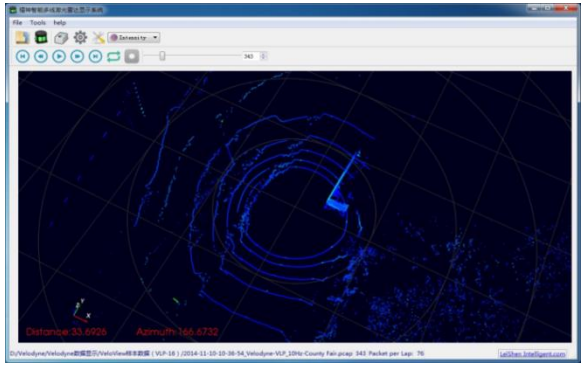
1) Function introduction of toolbar buttons

- Play **pcap,** an offline point cloud file

Click the Open File button  to pop up the dialog:



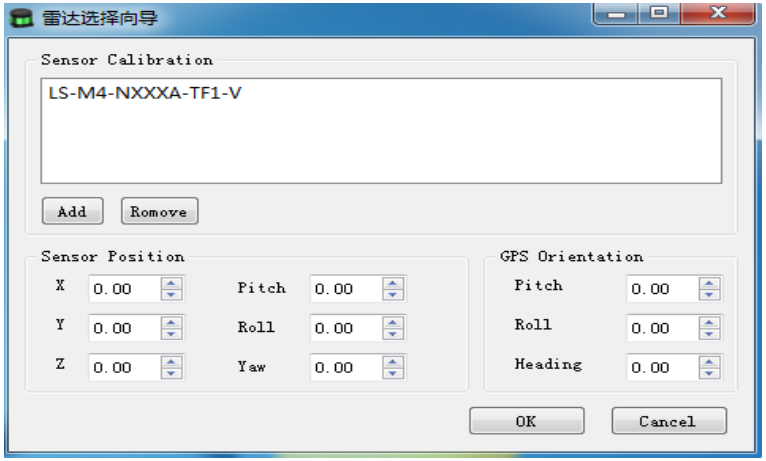
Select the pcap file to be played, and click the Open button. After file loading, it is shown as below:

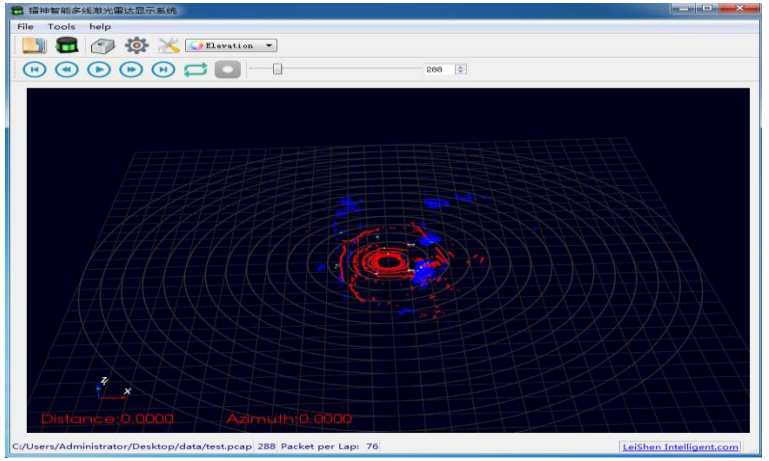


Click the button  to start playing the offline point cloud file pcap and visualizing the point cloud data.

- Introduction of real-time LiDAR data reception button

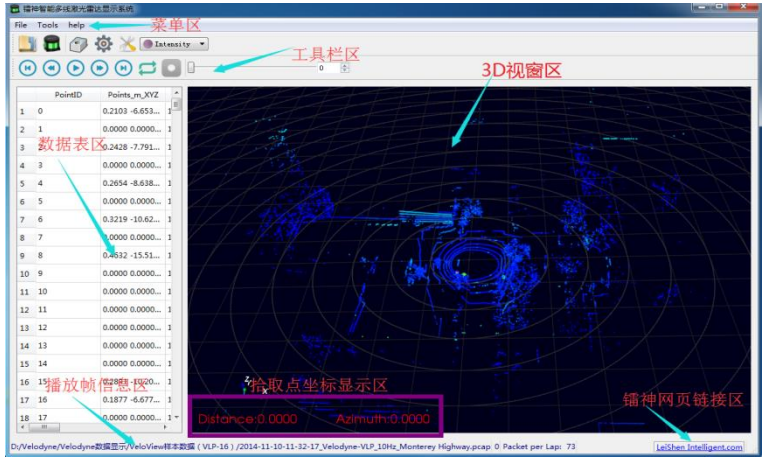
When the LiDAR power supply and network cable are connected, click the button  to enable real-time LiDAR data reception. Click the OK button in the pop-up LiDAR wizard interface so that the software automatically detects the reception of data, processes and displays real-time data. Click the Cancel button so that no LiDAR data display is received.





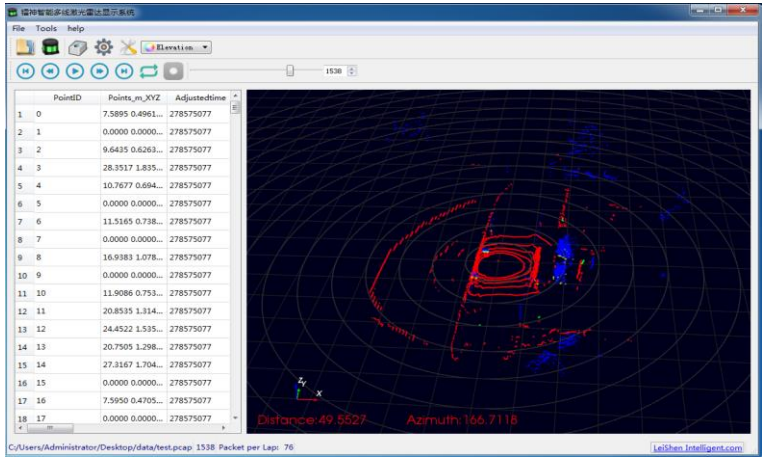
- Introduction of software interface:

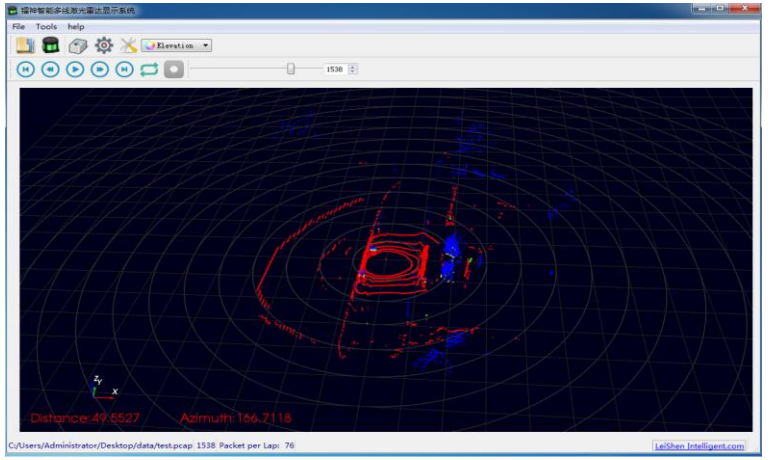
The software interface includes menu area, toolbar area, 3D window area, data sheet area, play frame information area, pick point information, and company website link. Each section is indicated as below:



- Data sheet Display/Hide button

Clicking the icon  displays or hides the data sheet. The effect chart is shown below. The shortcut key for data sheet Display/Hide button is Ctrl + T.





The data sheet contains (PointID, Points_m_XYZ, adjustedtime, Azimuth, Distance, Intensity, Laser_id, timestamp). In particular, PointID 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, adjustedtime 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 (5hz/10hz/20hz three speed modes can be selected under combobox), 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.

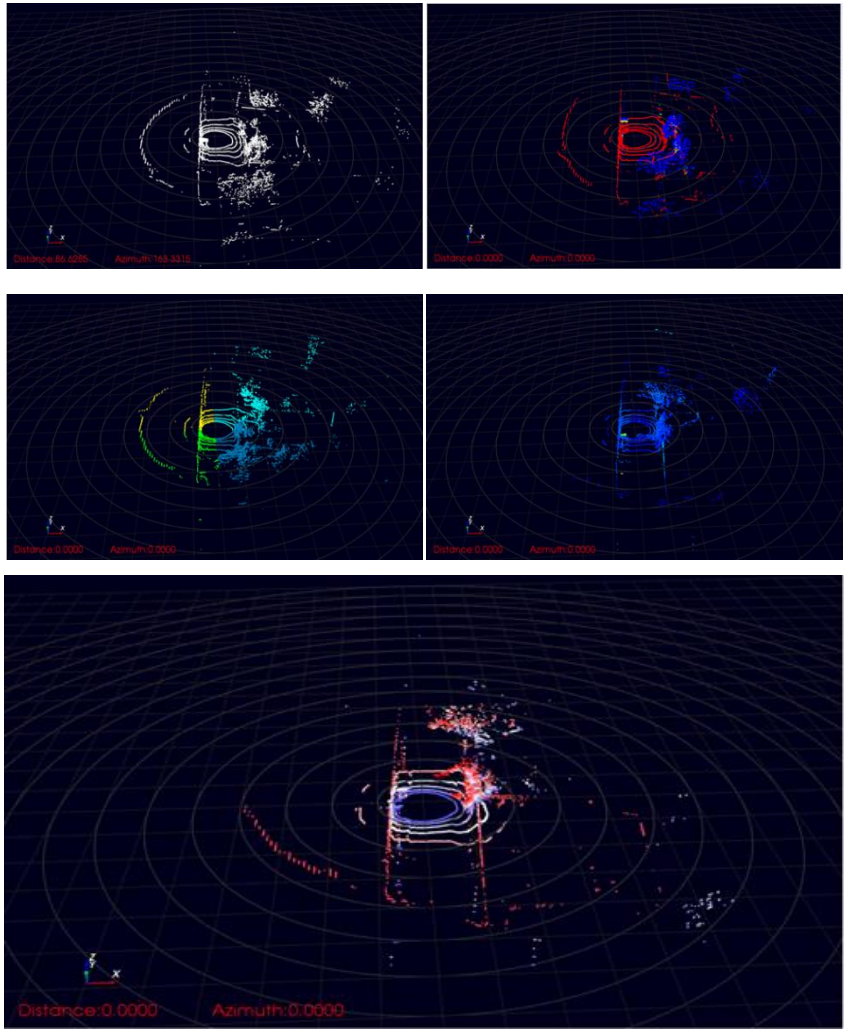
Clicking the Status Information Refresh allows to get the previous configuration information of the LiDAR (content of device information stream). After filling in the setting information, click the Settings button to send the UCWP packet to the LiDAR. When the LiDAR receives the UCWP packet, it is necessary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

- LiDAR display color scheme

Click the drop-down menu in icon 

to change the color of the point cloud in the visual point cloud area.

The color change of the point cloud in the visual point cloud area includes the following modes. The effect charts of the five modes - SolidColor, Elevation, Azimuth, Intensit and LaserID - are as follows:



Specifically, the point cloud in SolidColor mode is a white point; in Elevation mode, there is a gradual color change from blue to red based on the elevation values of point cloud; in Azimuth mode, the four colors of deep blue, light blue, green and yellow are assigned according to the angle values; in LaserID mode, there is a gradual color change from purple to white by the channel number of point cloud; in Intensity mode, there is a gradual color change from purple to red based on the reflection intensity values.

- Introduction of play related buttons

Click the button  to return to the data start frame.

There are two circumstances in clicking the button  or  :

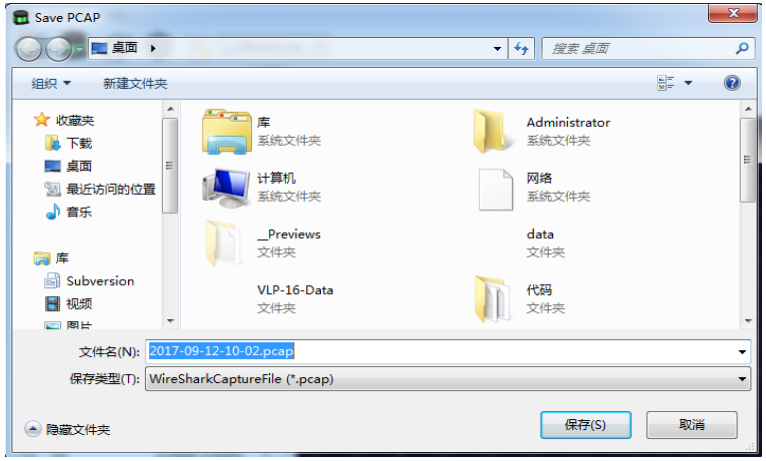
1. In case of pause, clicking the button is able to jump to the previous/next point cloud data.

2. In case of play, clicking the button enables to play in reverse/positive sequence (by clicking multiple times, it is able to choose different speeds, including 2x, 3x, 1/2x, 1/4x and 1x)

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

Click the button  so that the view jumps to the end of the file.

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:

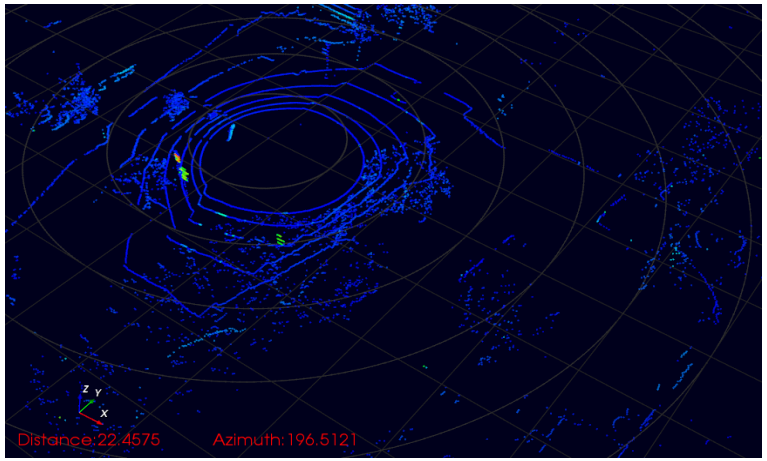


Clicking  again stops storing.

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 addition to the point cloud data, there are 15 gray circles and 31 × 31 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 150m. Grids and auxiliary circles make it easy for users to see the location of point cloud.

The pick point (the current position of the mouse) information shown in the lower left corner of the display interface indicates the angle (unit: degree) and distance (unit: m) values of the pick point relative to the origin on the X-Y plane. 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:

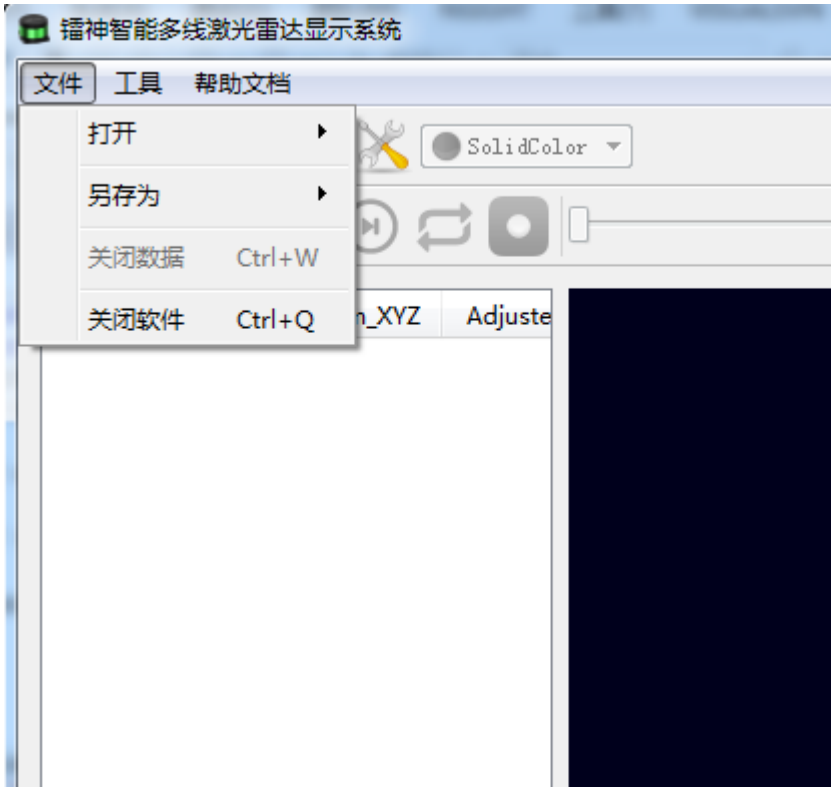
1. By moving the mouse wheel the display interface zooms in/out; holding down the right mouse button to drag up/down can also do.

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.

2) Function introduction of menu bar buttons

- File Menu



There are two options under the Open menu. Open -> Open Offline File menu has the same function as the Open File button  referred to in the Section 1 Function introduction of toolbar buttons of Chapter 4. Open -> LiDAR Data Stream menu has the same functions as the Receive Real-time LiDAR Data  button referred to in the Section 1 Function introduction of toolbar buttons of

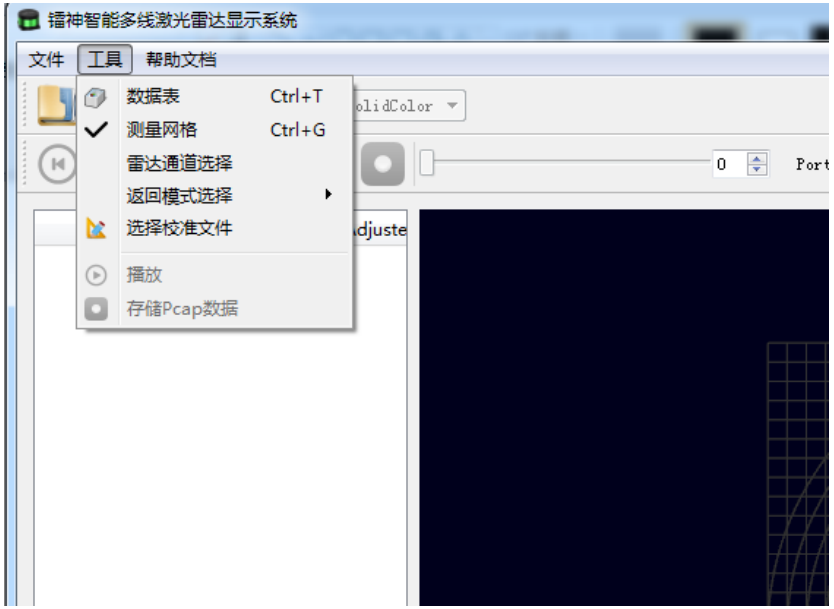
Chapter 4.

Save As menu can saves the current frame data as data file in CSV format. This function can only be used when the LiDAR data is received in real time and in playback mode. The information in the CSV file includes coordinate points Points_mXYZ:0, Points_mXYZ:1, Points_mXYZ:2, intensity, laser_id, azimuth, distance_m, adjustedtime and timestamp. In specific, Points_mXYZ:0, Points_mXYZ:1 and Points_mXYZ:2 are the values of the space coordinates (x, y, z), respectively; intensity represents point reflection intensity, laser_id the LiDAR channel number, djustedtime the adjusted time and timesstamp the current LiDAR time stamp.

Close Data menu functions to clear the real-time LiDAR data in the current view or offline file data views, with shortcut key of Ctrl + W.

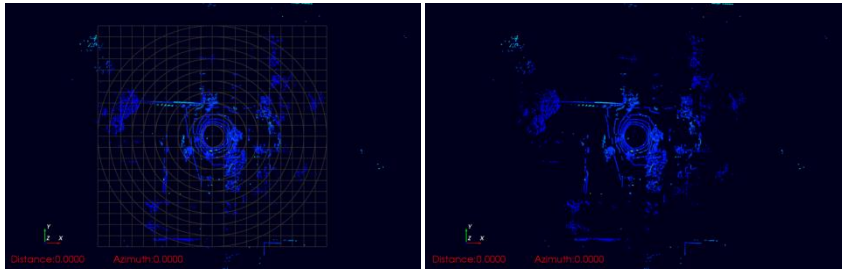
Close Software menu is used to close the current program interface and LeiShen multi-line lidar display system software, with shortcut key of Ctrl + Q.

- Tool menu

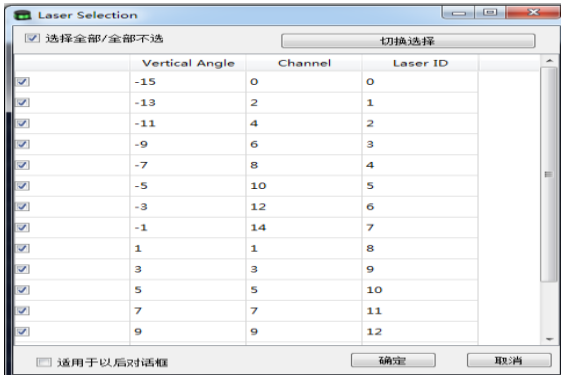


Datasheet menu has the same functions as the data sheet Display/Hide button  referred to in the Section 1 Function introduction of toolbar buttons of Chapter 4.

Measuring Grid menu is used to display and hide measuring grids and auxiliary circles. The effect charts are as follows:



LiDAR Channel Selection menu offers a choice to display/hide the data in one of the 16 channels. By clicking, the following interface will pop up;

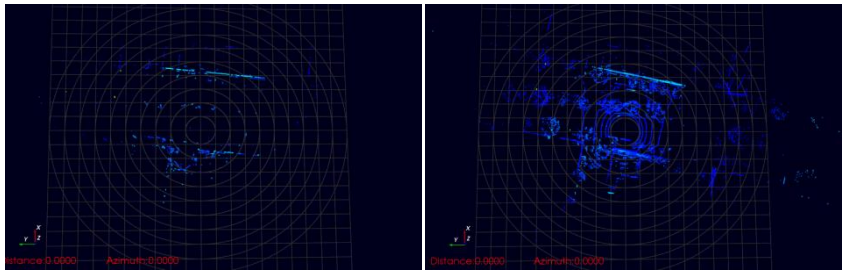


Clicking the check boxes on the left is able to close (open) a data channel, and clicking the Select All/Select None in the upper left corner is able to open (close) data in all channels.

Clicking the Apply in Future Dialog in the lower left corner is able to record the current selection state of the LiDAR harness for future application.

Vertical Angle in the form is the vertical angle of the corresponding channel data, channel the serial number of the data corresponding to the channel, and Laser ID the channel number of the LiDAR.

As shown below, the left shows data in some channels of the hidden 16 channels, and the right shows the complete data:



Return Mode Selection menu can only be used when the second echo LiDAR data is accessed. The three options in the menu - dual echo mode, strongest echo mode and only second echo mode - mean the LiDAR displaying Dual data (two echoes data), or Strongest data

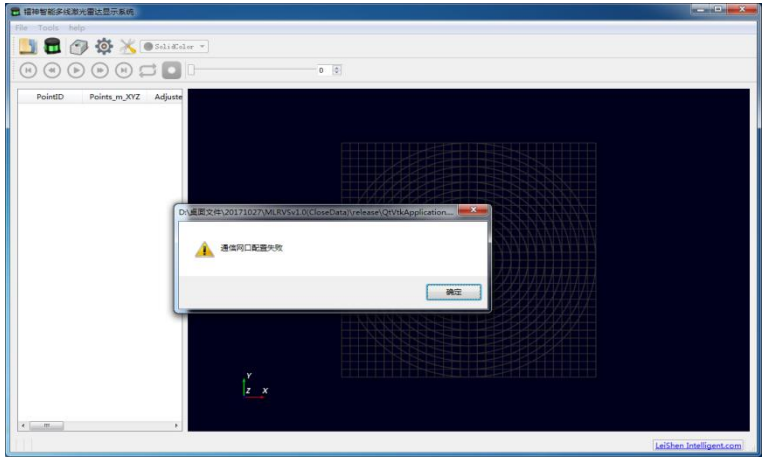
(only the strongest echo data) or only the second trip echo data respectively in the 3D window area.

Play and Storage menus have the same functions as the Play button  and Store Data button  referred to in the Section 1 Function introduction of toolbar buttons of Chapter 4.

Attention

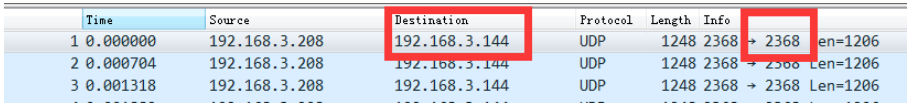
1. LiDAR setup and use issues:

(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.

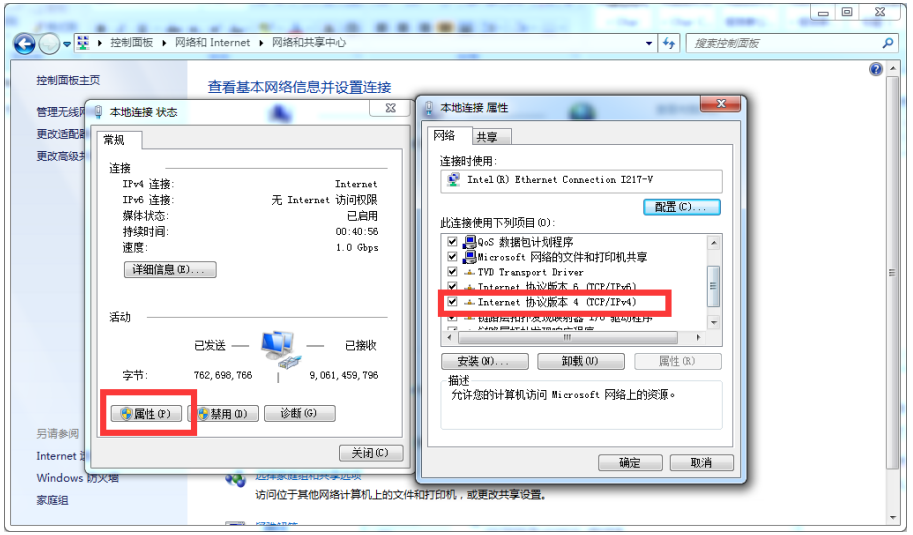
(2) As LeiShen 16-line lidar is able to modify the port number through the user configuration so that the LiDAR sends data to the upper computer through the preset destination IP and port, **it is necessary to set the IP as the destination IP of the LiDAR when the local notebook or desktop and other 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:



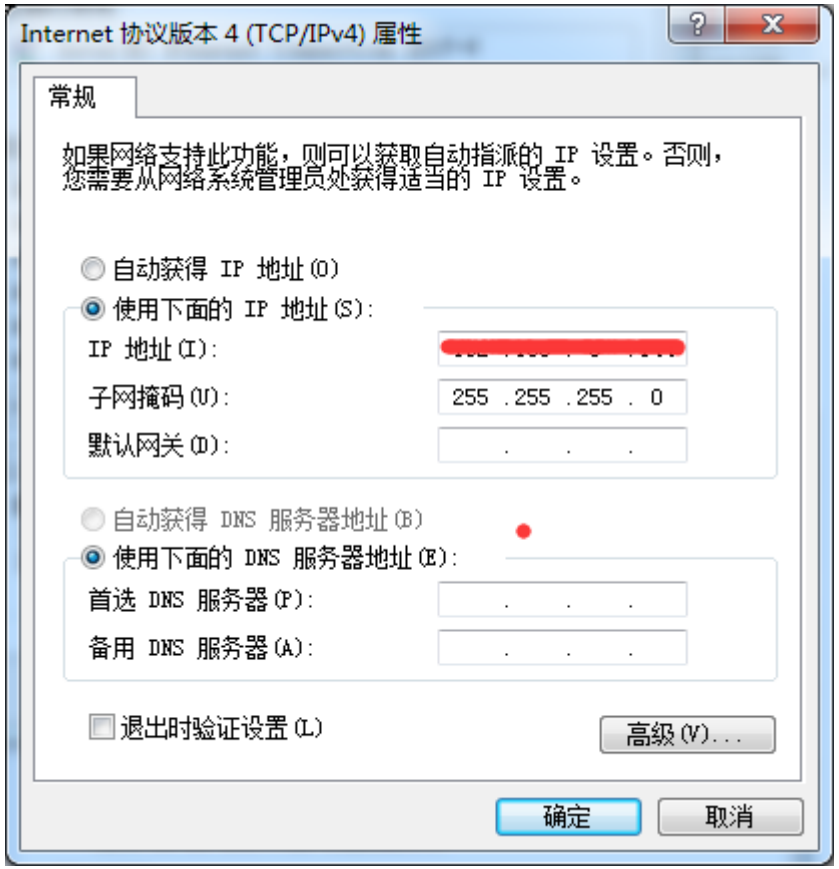
The red boxes indicate the destination IP and port of the LiDAR, respectively.

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

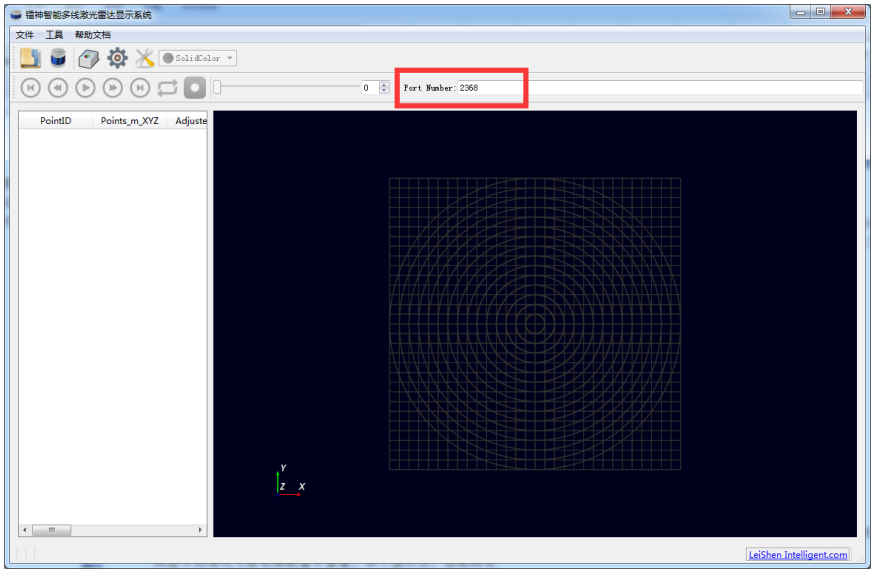
Click Properties in the pop-up status box and click TCP/IP4 Protocol Version in the pop-up Properties box, as shown below.



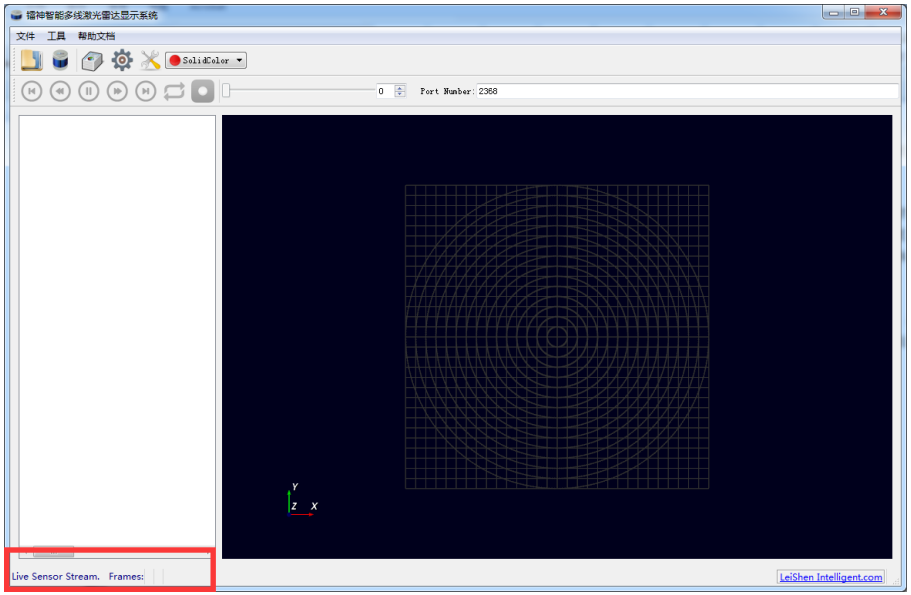
In TCP/IP4 Properties Settings set the IP address to the destination IP of the LiDAR (the default factory IP and port of the LiDAR are shown in the LiDAR communication protocol) and the subnet mask to 255.255.255.0.



In the local upper computer, a port number box is reserved in the toolbar. Users need to fill in the port number before clicking the Get Data button (the software will populate the default port number 2368). See the following figure for details:

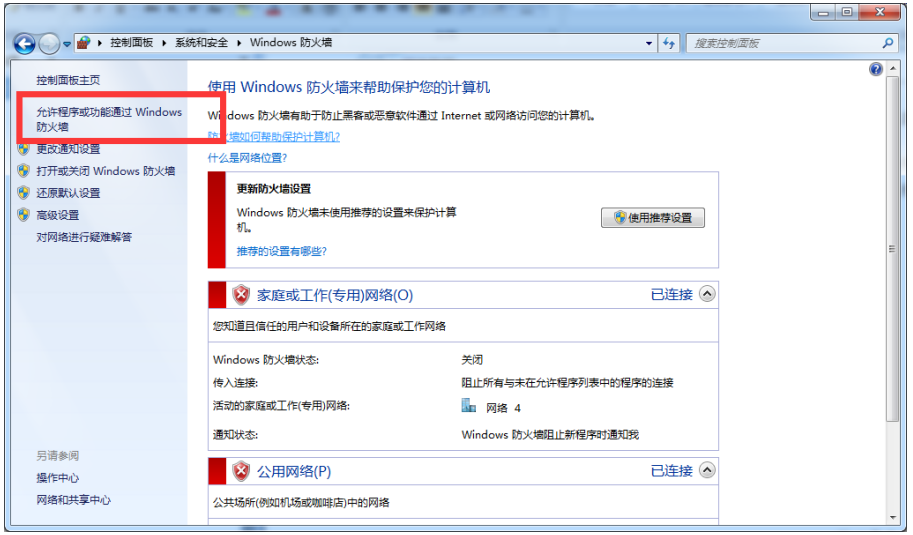


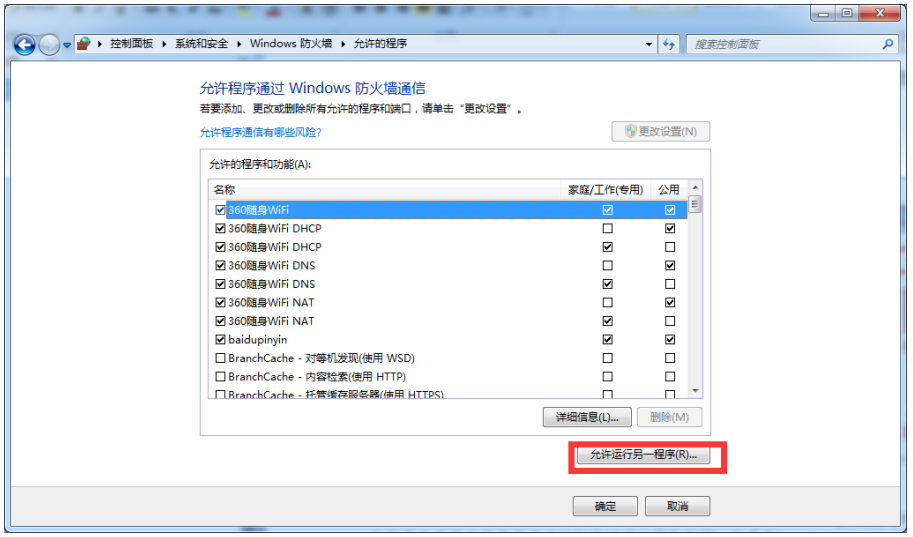
(3) Since LeiShen multi-line LiDAR display system program needs to acquire massive packets via the Internet in a short period of time, it may be prohibited by the network firewall as a malicious program. It is possible that packets are seen to have been sent to the computer using software wireshark to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

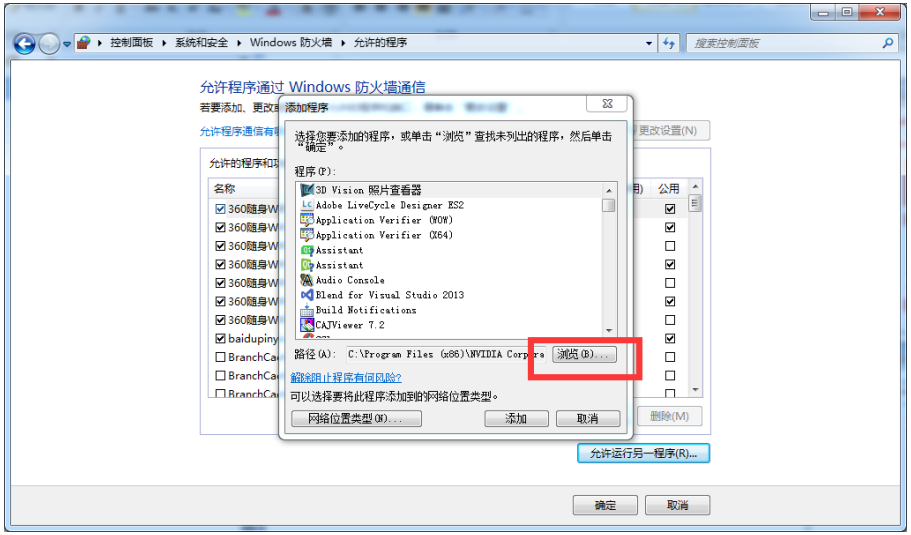


Prompt message appearing in the lower left corner means the upper computer has started to get data but has not got the packet.

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







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.

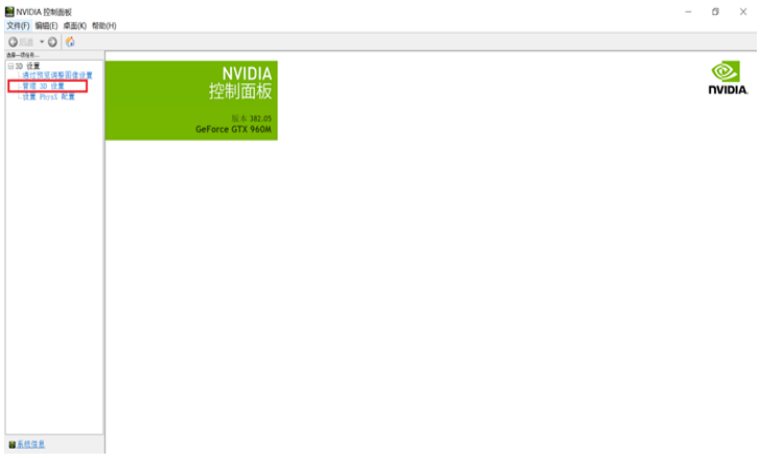
2. When LeiShen Intelligent multi-line lidar display software is installed in a desktop or laptop with dual GPUs, the default global settings for the computer operating system as use global settings (automatic selection: integrated GPU) have an effect on the display efficiency of the software. To ensure the use and display efficiency of the software, it is necessary to manually 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 manually adjust the settings by switching the applicable GPU of the software manually 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.

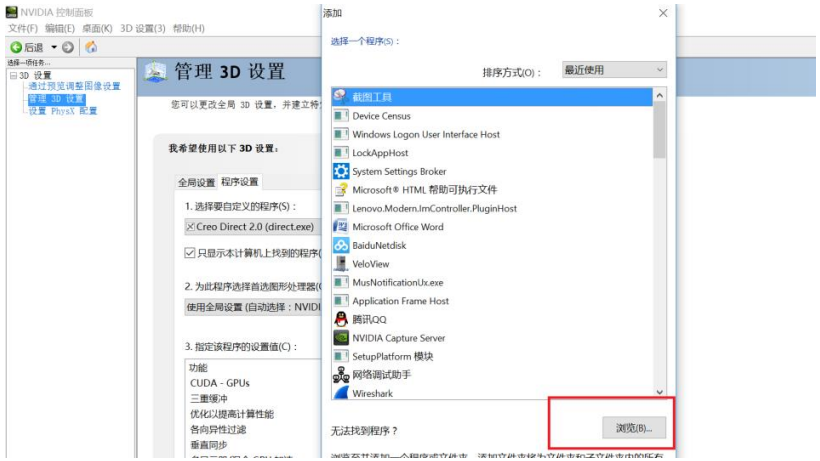
2. Select Manage 3D Settings button in the pop-up program interface of NVDIA Control Panel, as shown below.



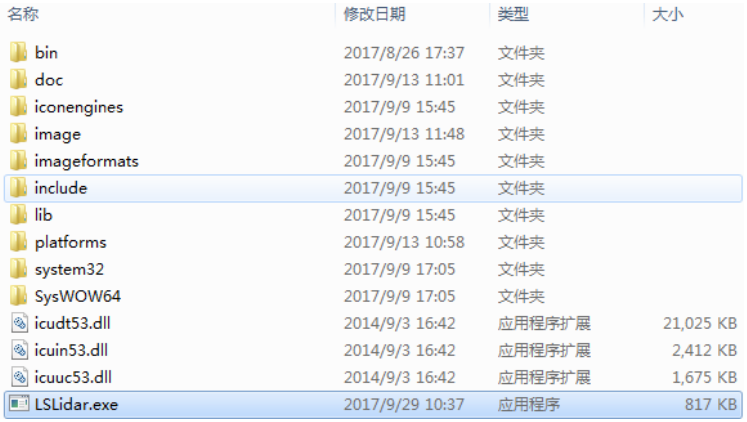
3. Select Program Settings button in Manage 3D Settings interface, as shown below.

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

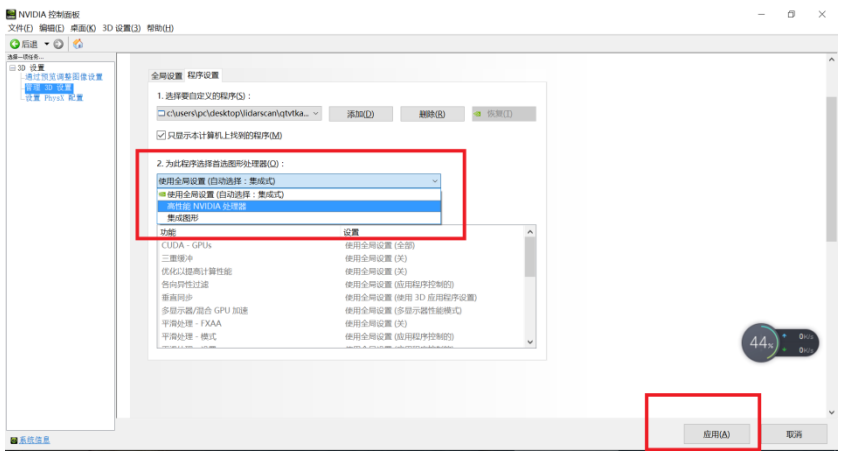
5. Click Browse button in the pop-up Add interface, as shown below.



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.

Remaks: Local IP and destination IP should not be set as the same, otherwise Lidar will not work properly.

Table 1 Factory Default Network Configuration

	IP	Port number
LiDAR	**192.168.1.200**	**2368**
Computer	**192.168.1.102**	**2368**

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.

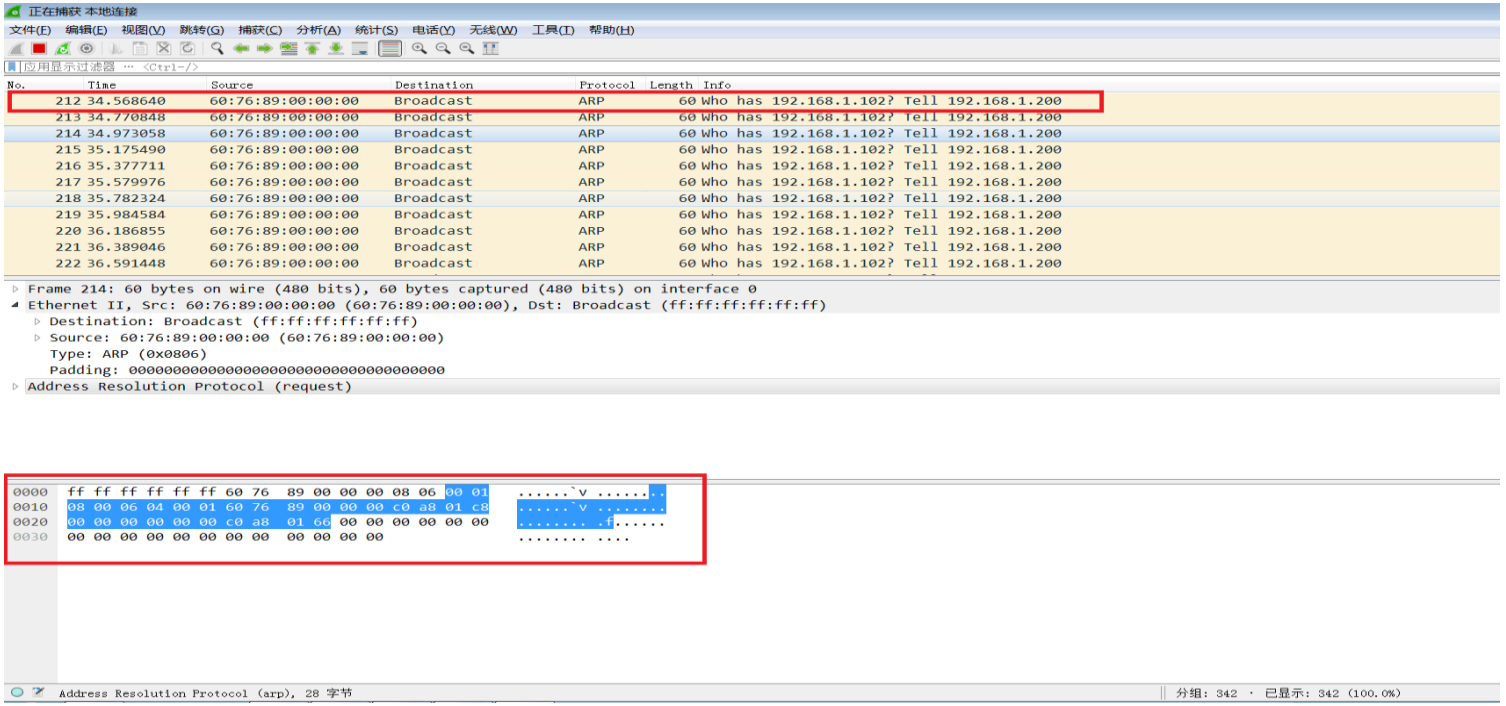


Figure 1 Wireshark Capturing ARP packet

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 according to their needs;

Table 2 Device Protocol List

(Protocol/packet) name	Abbreviation	Function	Type	Packet size	Transmission interval
Main data Stream Output Protocol	MSOP	Outputting scanned data	UDP	1248byte	About 0.6ms
Device Information Output Protocol	DIFOP	Outputting device information	UDP	1248byte	About 100ms
User Configuration Write Protocol	UCWP	Inputting user configured device parameters	UDP	1248byte	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/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.

1.1 Packet data structure form

In the current 16-line lidar second echo mode, two echo data are returned. The information of two transmission sequences from 16 lasers is contained in one data block. The first and second data blocks are two echo data in the same sequence, and so on. Each packet contains data of 12 transmission sequences. Only one azimuth is returned per data block. See the figure below:

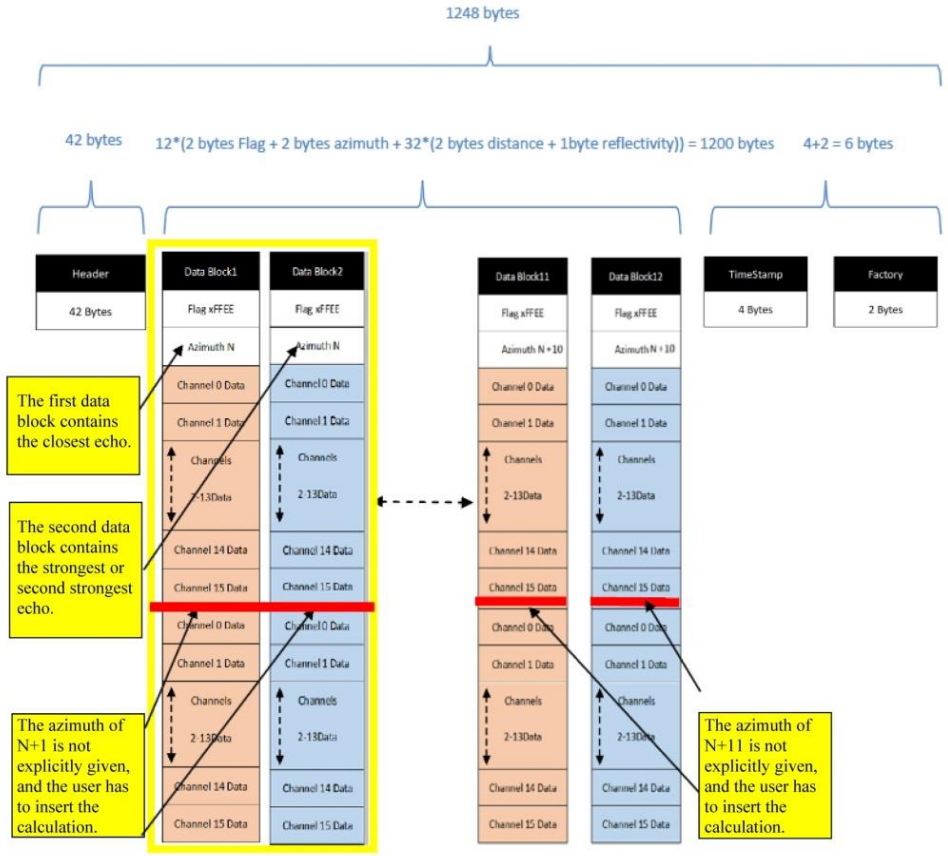


Figure 3 Second Echo Packet Data Structure Form

- The sensor provides the closest echo and the strongest echo/second strongest echo;
- The sensor transmits a pair of data blocks for each azimuth;
- If the closest echo is the strongest one, the second strongest echo is provided as the second echo;
- 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;

1.2 Frame header

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

1.3 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. The 16 channels are packeted in such order as described by the channel number: 0, 8, 1, 9, 2, 10, 3, 11, 4, 12, 5, 13, 6, 14, 7 and 15. The channel numbers are shown below.

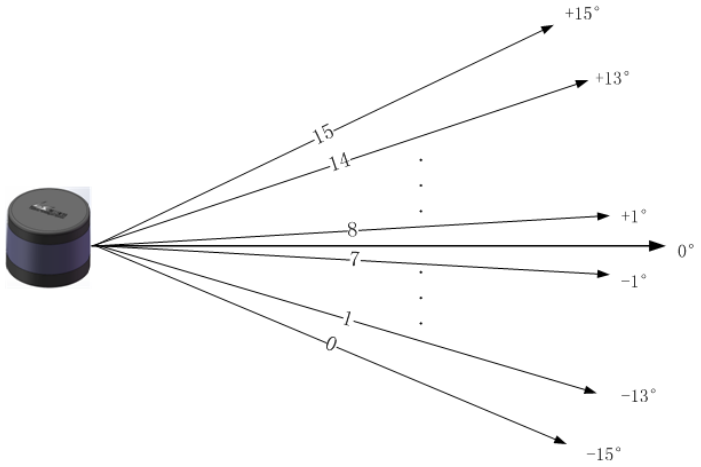


Figure 4 Distribution of 16 Optical Channels

1.3.1 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) (0.1 °, 0.2 °, 0.4 °). 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

Laser ID	Vertical Angle
0	-15 °
1	-13 °
2	-11 °
3	-9 °
4	-7 °
5	-5 °
6	-3 °
7	-1 °
8	1 °
9	3 °
10	5 °
11	7 °
12	9 °
13	11 °
14	13 °
15	15 °

As shown in Figure 3, there is only one angle value between the Nth data block and the N+1th data block of second echo 16-line lidar. The Nth data block contains two measurements of the closest echo, and the N+1th data block contains two measurements of the strongest second echo. However, the Nth data block and

the N+1th data block are actually data of two measurements. Therefore, the data need to be interpolated. The interval between each measurement is equal, and the angle rotates at a constant speed. The interval of data block is the same for each two groups. The two adjacent angle values (Azimuth N and Azimuth (N + 1)) are averaged as the horizontal angle values for the second group of measurement 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.

1.3.2 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.

Table 4 Channel Data Diagram

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

1.4 Frame tail

Tail is 6byte long, 4byte for Timestamp and 2byte for Factory.

Table 5 Timestamp Storage Data Format

	Timestamp memory (Timestamp1,243 - 1,246byte position)			
S/N	**Byte1**	**Byte2**	**Byte3**	**Byte4**
Function	**microsecond**			

Table 6 Factory Bytes

Factory bytes (1,247 - 1,248)		
S/N	**Byte1**	**Byte2**
Function	**Return Mode**	**Device Type**

Meaning for Byte Content

Filed 4DEh		Filed 4DEh	
Value	**Meaning**	**Value**	**Meaning**
37h	**Strongest Return**	**20h**	**C16**
39h	**Dual Return**		

Device Information Output Protocol (DIFOP)

Device Information Output Protocol, referred to as: 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	S/N	60	6
	9	Firmware version	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.

The Tail contains 0x0F and 0xF0.

Motor speed is defined in 3.1; **Ethernet** is defined in 3.2; **time** is defined in 3.3; **serial number** is defined in 3.4; **firmware version** is defined in 3.5; **LiDAR rotation/silence** is defined in 3.6; **number of intervals at which device information stream sends packets** is defined in 3.7; **compatible with Velodyne** is defined in 3.8; **longitude and latitude** is defined in 3.9.

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. **Local IP and destination IP should not be set as the same, otherwise Lidar will not work properly.**

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
Data	1	Motor speed	8	2
	2	Ethernet	10	26
	3	Reserved	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	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.

3.1 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.

3.2 Ethernet

Table 10 Ethernet Register Definition

Ethernet register (26byte)								
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						port1	
S/N	byte17	Byte18	Byte19	Byte20	Byte21	Byte22	Byte23	Byte24
Function	Port2		Port3		Port4		Port5	
S/N	Byte25	Byte26						
Function	Port6							

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 - port6 are port number information; port1 is the UDP local port number, and port2 is the UDP destination port number.

3.3 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					

7) ms

reg name：set_ ms								
S/N	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8
Function	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	ms[9:8]	
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_ms[7:0]							

Note: set_ms[9:0] value range: 0 - 999

8) us

reg name：set_us								
S/N	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8
Function	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved	us[9:8]	
S/N	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_us[7:0]							

Note: set_us[9:0] value range: 0 - 999

3.4 Serial number

Table 12 Serial Number Byte Definition

Serial number byte (6byte)			
S/N	**Byte1~Byte2**		**Byte3~ Byte6**
Function	**Line number**	**Operating distance**	**No.**

Line number:

Line number vs No.							
No.	**0x00**	**0x01**	**0x02**	**0x03**	**0x04**	**0x05**	**0x06**
Line number	**C4**	**C8**	**C16**	**C32**	**C48**	**C64**	**C128**

Operating distance (in m):

Operating distance vs No.				
No.	**0x00**	**0x01**	**0x02**	**0x03**
Operating distance	**701**	**121**	**151**	**201**

No. ----- 4byte No. range 0x00000000 - 0xFFFFFFFF.

For example, the channel data of a packet is calculated as follows: 0x02 0x01 0x00000023.

Interpretation: 16-line navigation type 120m first generation No. 35 device

3.5 Firmware version

Table 13 Firmware Version Byte Definition

Firmware version byte (4byte)				
S/N	**Byte1**	**Byte2**	**Byte3**	**Byte4**
Function	**V**	**1**	**0**	**0**

Example: V 1.0.0

3.6 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.

3.7 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**	

Obtain the hexadecimal number for the values of the data packet: 0x00 and 0xA6.

Combine the data into 16bit unsigned integer data, expressed as: 0x00A6.

Convert segment coefficient values to decimal number: 166.

Produce the interval at which packets are sent: 166.

3.8 Compatible with Velodyne

Table 16 Compatible with Velodyne Byte Definition

Compatible with Velodyne byte (2byte)		
S/N	Byte1	Byte2
Function	Signal flag	

It is compatible with Velodyne when the transmitted signal flag is 0x ABCD. **No device information output protocol is available when the LiDAR is re-powered after outage**. Velodyne upper computer software can be used directly to display the point cloud data. When the transmitted signal flag is 0x0000, the restarted LiDAR still sends the device information output protocol after outage.

3.9 Longitude and latitude

Table 17 Longitude and Latitude Byte Definition

Longitude and latitude byte (22byte)								
S/N	**byte1**	**Byte2**	**Byte3**	**Byte4**	**Byte5**	**Byte6**	**Byte7**	**Byte8**
Function	**Latitude (byte1 is the discarded byte, and 9 bytes from byte2 to byte10 are latitude values)**							
S/N	**Byte9**	**Byte10**	**Byte11**	**Byte12**	**Byte13**	**Byte14**	**Byte15**	**Byte16**
Function			**Longitude (10 bytes from byte11 to byte20 are longitude values)**					
S/N	**byte17**	**Byte18**	**Byte19**	**Byte20**	**Byte21**	**Byte22**		
Function	**Longitude value**				**Latitude north-south N/S**	**Longitude west-east W/E**		

Longitude and latitude output protocol, output in ASCII code.

3.10 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
port3 ~ port6	00,00,00,00，	0x00,0x00,0x00,0x00，	8

	00,00,00,00	**0x00,0x00,0x00,0x00**	
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	**166**	**0x00A6**	**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

Three 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, see 4.1 for details;

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, see 4.2 for details;

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, see 4.3 for details.

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 3.125us. 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.

4.1 GPS timing synchronization

C16 series Lidar can be synchronized through accurate time provided by GPS. GPS PPS is capable of calculating the 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

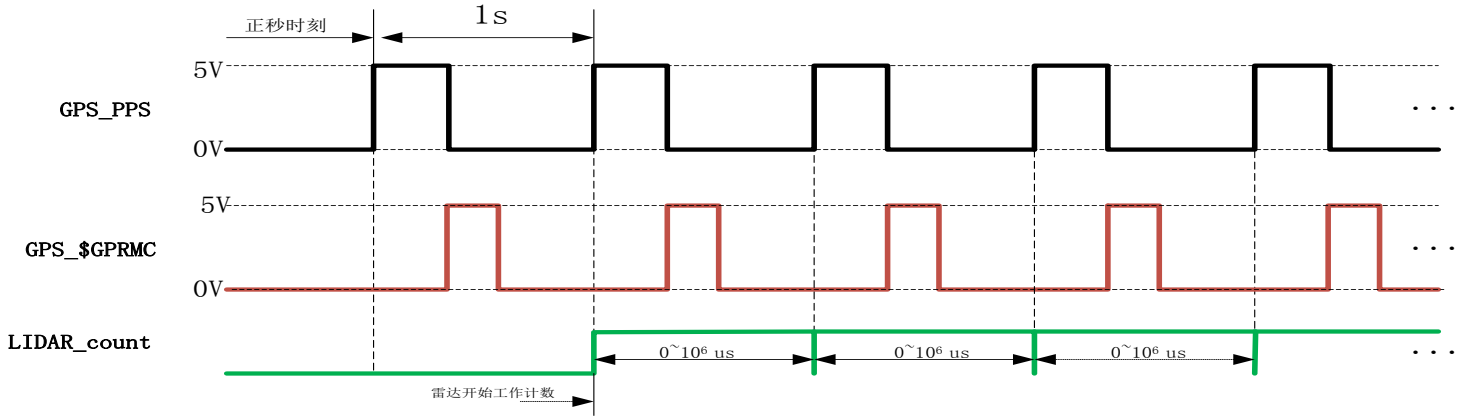


Figure11 GPS timing system signal timing diagram

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

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

$T_{\text{accurate time of 192nd pulse}}$-------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:

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

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

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	Timestamp	Factory
		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 Bytes	2 Bytes
			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		
First area	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		
	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		
Second area	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		
	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		

4.2 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;
- 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).

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, TimeOffsetn 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:

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

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

4.3 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. TimeOffsetn can be obtained from Table 19, the formula is as follow:

$$T_{\text{第 n 次脉冲准确时间}}=T_{\text{第 192 次脉冲准确时间}}+\text{TimeOffset}_n-596.875\text{us（n 为 1~192）}$$

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

or it can be expressed as:

$$T_{\text{第 n 次脉冲准确时间}}=T_{\text{第 192 次脉冲准确时间}}+\text{（n-1）*3.125us}-596.875\text{us（n 为 1~192）}$$

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

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

LeiShen Intelligent System LiDAR

LeiShen Makes A Better World !

LeiShen Intelligent System Co .,LTD.

Headquarter & R&D Center Address: Floor 4, Yunhua Times, Bogang Avenue, Shajing, Bao'an District, Shenzhen.

Factory Address: F6, TaiJiaLe Industrial Park, Tongguan Road, Tianliao Community, Gongming, Guangming New District, ShenZhen.

Xidian & LeiShen Joint Laboratory: No.2 Taibai South Road, Xi’ an, Shanxi Province

Tel : 0755-27190511 ; 0755-23242821

Fax : 0755-23244803 ; 0755-23214316

Website : www.leishen-lidar.com

E-mail : sales@lslidar.com

Rev 2.5 Aug.2018