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Revision History

Revision	Content	Date	Edited by
1.0	Initial release	2017-03-01	RD
3.0	Fill in the content according to RS-LiDAR-16 1.0 hardware.	2017-05-10	RD
3.1	Modify the relationship between laser channel and vertical angle	2017-06-13	PD
3.2	Update the content according to RS-LiDAR-16 2.0 hardware Add the timestamp calculation method for every point	2017-07-17	PD
3.3	Improve the range to 150m Delete the description that MAC addressing is the same as serial number Add azimuth interpolation calculation method Corrected the data structure of UCWP Add the instruction for RSVIEW Add the instruction for ROS driver	2017-08-10	PD
3.4	Add the frame description for ROS driver Add the RS-LiDAR information in RSVIEW	2017-08-23	PD
3.5	Correct the description for horizontal resolution Add the description for LiDAR mechanical origin	2017-09-16	PD
3.6	Update the RS-LiDAR information and data port setting Update the protocol description of DIFOP	2017-12-05	PD
3.7	Correct the depth dimension of the mount hole Add Phase Lock Add fault diagnosis Add operation status	2018-02-05	PD
3.8	Add trouble shooting	2018-03-15	PD
4.0	Add LiDAR flag for MSOP Update DIFOP protocol Add top and bottom board flag description Add GPS input status flag Add laser mechanical position Add bottom board firmware online update Add fault diagnosis usage Add LiDAR installation suggestion	2018-06-25	PD

4.1	Add the sensor clean instruction Add the RSVIEW compatible instruction Add the LiDAR cable route instruction	2018-08-04	PD
4.2	Refine LiDAR power supply considerations Add the instruction of space between the LiDAR and mounting brackets Modify the DIFOP data format Add laser eye safety level instructions Add aviation connector description and definition Add Interface Box connection diagram Update GPS synchronization protocol description Add RS232 to TTL adapter wiring diagram and PIN definition Add return mode description Add information to fault diagnosis Modify the UCWP data format and add the FOV setting description Update Appendix C RSView content Add the description of distance resolution 0.5cm Add the description of intensity mode 3	2019-04-25	PD
V4.3	This version of the manual is applicable to radars of V4.0 and later versions. For radars of previous versions of V4.0, please refer to the manual of version 4.2. Modify the definition and schematic diagram of the air interface Add the cleaning reminder in harsh environments Adapted to the V4.0 version of the LiDAR, the number of points per second is modified from 320000/s to ~300000/s Adapted to the V4.0 version of the LiDAR, the horizontal resolution of the point cloud is modified from 0.09° -0.36° to 0.1° -0.4° Change the working temperature to -30°C -60°C Adapted to the V4.0 version of the LiDAR, at the accurate point time calculation in Appendix A, the transmission interval between the channels of the device is changed from 3 μs to 2.8 μs, and the block time is changed from 50 μs to 55.5 μs Add description of replacing LiDAR configuration file in Ubuntu system	2019-07-10	PD

	Add GPS interface PIN definition of the V4.0 version LiDAR's interface box		
4.3.1	Update electrical interface diagram Add "LiDAR" to the network wiring definition		
4.3.2	Correct some description faults Add LiDAR mechanical installation suggestion Update download address of RSView Add LiDAR dimension diagram Add footnote for specification in chapter 3	2019-12-11	PD
4.3.3	Replace the dimension drawing in Appendix E Modify some descriptions	2020-02-18	PD

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Terminologies

MSOP	Main Data Stream Output Protocol
DIFOP	Device Info Output Protocol
UCWP	User Configuration Write Protocol
Azimuth	Horizontal angle of each laser firing
Timestamp	The marker that records the system time
Header	The starting part of the protocol packet
Tail	The ending part of the protocol packet

Congratulations on your purchase of a RS-LiDAR-16 Real-Time 3D LiDAR Sensor. Please read carefully before operating the product. Wish you a pleasurable product experience with RS-LiDAR-16.

1 Safety Notices

To reduce the risk of electric shock and to avoid violating the warranty, do not open sensor body.

- **Laser safety** - The laser safety complies with IEC 60825-1:2014.
- **Read Instructions** - All safety and operating instructions should be read before operating the product.
- **Follow Instructions** - All operating and use instructions should be followed.
- **Retain Instructions** - The safety and operating instructions should be retained for future reference.
- **Heed Warnings** - All warnings on the product and in the operating instructions should be adhered to.
- **Servicing** - The user should not attempt to service the product beyond what is described in the operating instructions. All other servicing should be referred to RoboSense.

2 Introduction

RS-LiDAR-16, launched by RoboSense, is the first of its kind in China, world leading 16-beam miniature LiDAR product. Its main applications are in autonomous driving, robot-environment perception and UAV mapping.

RS-LiDAR-16, as a solid-state hybrid LiDAR, integrates 16 laser/detector pairs mounted in a compact housing.

Unique features include:

- Measurement range of up to 150 meters
- Within 2 centimeters measurement accuracy
- Data rate of up to 300,000 points/second
- Horizontal Field of View (FOV) of 360°
- Vertical Field of View (FOV) of 30° (-15°~+15°)

The compact housing of RS-LiDAR-16 mounted with 16 laser/detector pairs rapidly spins and sends out high-frequency laser beams to continuously scan the surrounding environment. Advanced digital signal processing and ranging algorithms calculate point cloud data and reflectivity of objects to enable the machine to "see" the world and to provide reliable data for localization, navigation and obstacle avoidance.

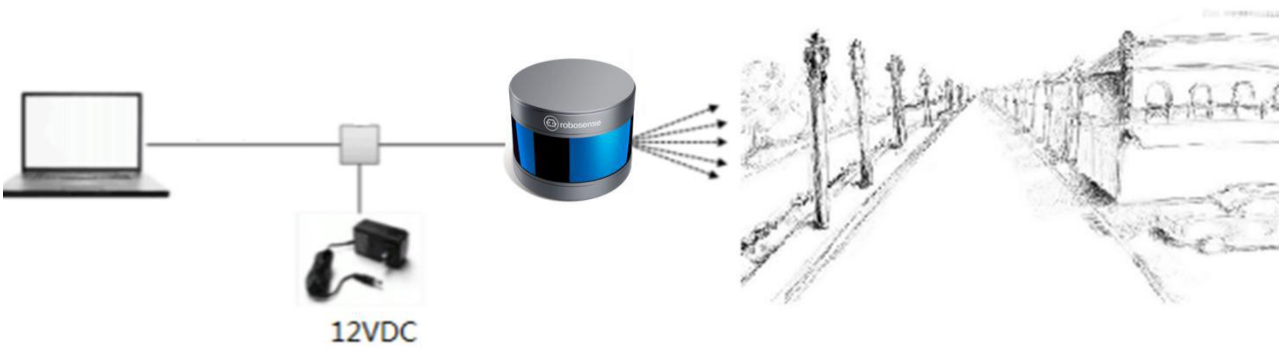


Figure 1: RS-LiDAR Imaging System.

Operation of device include:

- Establish communication with RS-LiDAR-16;
- Parse the data packets for azimuth, measured distance, and reported calibrated reflectivity;
- Calculate X, Y, Z coordinates from reported azimuth, measured distance, and vertical angle;
- Store the data as needed;
- Read current device configuration data;
- Set Ethernet, time and rotational speed as needed.

3 Product Specifications[1]

3.1 Product Format

Table 1: Product Parameters.

Sensor	Time of Flight Distance Measurement 16 Channels Measurement Range: 40cm to 150m (on 20% reflectivity target)[2] Accuracy: ±2cm (typical, refer to Figure 2)[3] Field of View (Vertical): ±15.0° (30° in total) Angular Resolution (Vertical): 2° Field of View (Horizontal): 360° Angular Resolution (Horizontal/Azimuth): 0.1°(5Hz) to 0.4°(20Hz) Rotation Rate: 300/600/1200 rpm(5/10/20 Hz)
Laser	Class 1 Wavelength: 905nm Full Beam Divergence Horizontal: 7.4 mrad, Vertical: 1.4 mrad
Output	Data Rate: ~300,000 points/second 100Mbps Ethernet UDP packet, include: Distance Rotation Angle/Azimuth Calibrated Reflectivity Synchronized Timestamp (Resolution: 1us)

[1] The following data is only for mass-produced products. Any samples, testing machines and other non-mass-produced versions may not be referred to this specification. If you have any questions, please contact RoboSense sales.

[2] The measurement target of rang is a 20% NIST Diffuse Reflectance Calibration Targets, the test performance is depending on circumstance factors, not only temperature, range and reflectivity but also including other uncontrollable factors.

Mechanical/ Electrical/ Operational	Power Consumption： 12 W (typical)[4] Operating Voltage: 9-32 VDC (with Interface Box and Regulated Power Supply) Weight: 0.87 Kg (without cable) Dimensions: 109 mm Diameter X 80.7 mm Height Environmental Protection: IP67 Operation Temperature: -30 ℃ to +60 ℃[5] Storage Temperature: -40 ℃ to +85 ℃

3.2 Accuracy

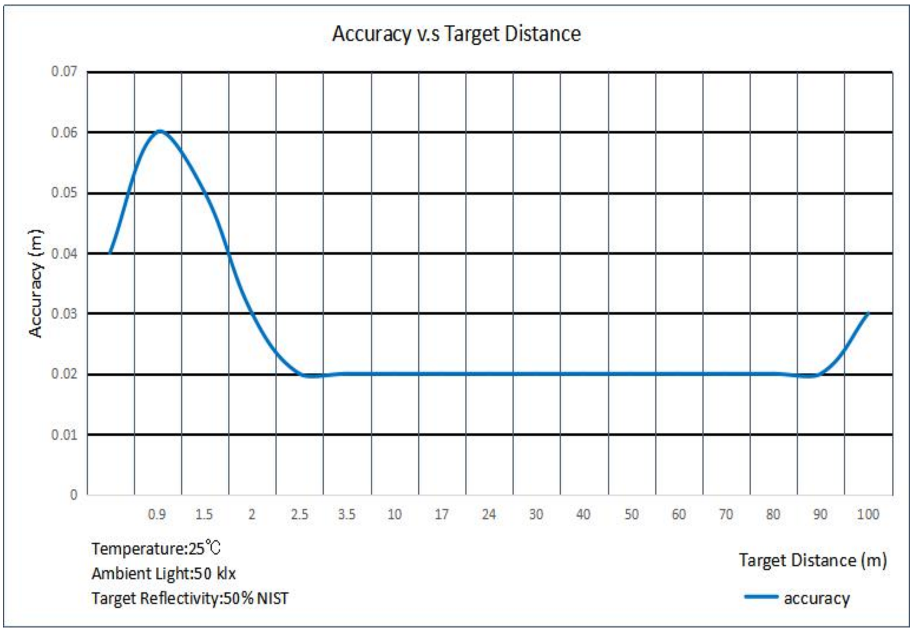


Figure 2: The Relation between accuracy and distance of target object.

[3] The measurement target of accuracy is a 50% NIST Diffuse Reflectance Calibration Targets, the test performance is depending on circumstance factors, not only temperature, range and reflectivity but also including other uncontrollable factors.

[4] The test performance of power consumption is depending on circumstance factors, not only temperature, range and reflectivity but also including other uncontrollable factors.

[5] Device operating temperature is depending on circumstance, including but not limited to ambient lighting, air flow and pressure etc.

4 Connections

4.1 Power

When equipped with an interface box, the device requires a voltage range of 9-32 VDC, and 12 VDC is recommended.

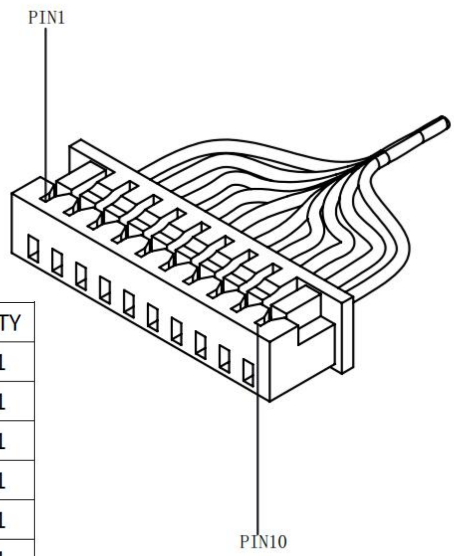
If the interface box is not used for the LiDAR, a regulated 12 VDC must be used, while the V4.0 and later versions of the LiDAR integrate the wide-voltage function internally, so you can continue to use 9-32 VDC.

The power consumption of the device is about 12 W (typical).

4.2 Electrical Configuration

RS-LiDAR-16 comes with an integral cable(power/data) that is permanently attached to the sensor and terminates at a standard SH1.25 wiring terminal. Figure 3 illustrates the serial PINs and their properties.

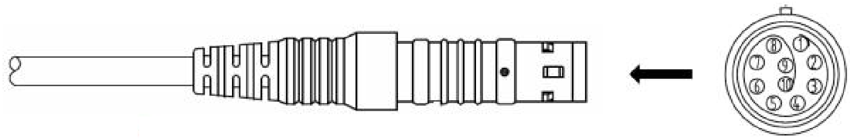
To operate RS-LiDAR-16, the user should insert the SH1.25 wiring terminal to the corresponding port on the Interface BOX.



ITEN NO.	CABLE COLOR	DESCRIPTION	QTY
1	Blue	GPS REC	1
2	Green	GPS PULSE	1
3	Red	+12V	1
4	Yellow	+12V	1
5	White	GND	1
6	Black	GND	1
7	Brown	LiDAR Ethernet RX-	1
8	Brown white	LiDAR Ethernet RX+	1
9	Orange	LiDAR Ethernet TX-	1
10	Orange white	LiDAR Ethernet TX+	1

Figure 3: Wiring Terminal and Serialized PIN.

The RS-LiDAR-16 has a type that uses the aviation connector. The cable length between the LiDAR and the aviation connector is 1 meter. The specific PINs of the aviation connector are defined as follows:



PIN	Wire Color	Function
1	Red	+12V
2	Yellow	+12V
3	White	GROUND
4	Black	GROUND
5	Green	GPS PULSE
6	Blue	GPS REC
7	Brown	LiDAR Ethernet RX-
8	Brown white	LiDAR Ethernet RX+
9	Orange	LiDAR Ethernet TX-
10	Orange white	LiDAR Ethernet TX+

Figure 4: Aviation Plug PIN Number.

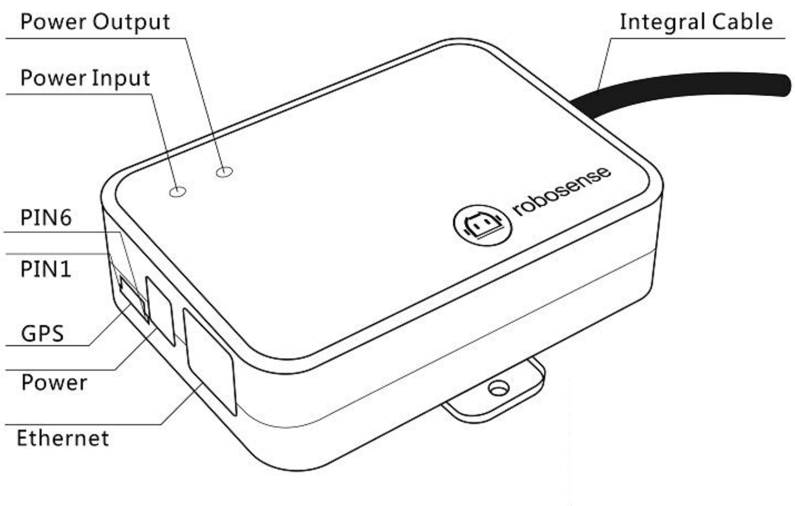
4.3 Interface Box Description

The Interface BOX is connected to the RS-LiDAR-16 by default.

The Interface BOX provides indicator LEDs for power, interfaces for power, 100Mbps Ethernet, and GPS inputs. The DC 5.5-2.1 connector for power input, RJ45 Ethernet connector for RS-LiDAR-16 data output and SH1.0-6P female connector for GPS input.

***Note**: The default cable of the interface box is 3 meters long, if you have other length requirements please contact the RoboSense technical support. Because of the different LiDAR versions, there are two definitions and different levels of the GPS port on the interface box.*

The corresponding positions of the interface are as follows (As shown in Figure 5):



PIN No.	V4.0 and later versions	Other versions
1	GPS PULSE	GPS REC
2	+5V	GPS PULSE
3	GND	GND
4	GPS REC	NC
5	GND	NC
6	NC	+5V

Figure 5: Interface definition on Interface Box.

Note: When RS-LiDAR-16 connects its grounding system with an external system, the external power supply system should share the same grounding system with that of the GPS.

On the Interface BOX, the red light indicator means standard power input, and the green one means standard power output. The Interface BOX access protection status when the red light indicator lights up and green light indicator blacks out. If the red and green light indicators blink at the same time, please check for errors of the power supply. If the power supply is checked without error, the high chance is that the Interface BOX is damaged. Please return damaged Interface BOX to RoboSense for service.

GPS interface definition: GPS REC means GPS UART input, GPS PULSE means GPS PPS input.

Ethernet interface complies with EIA/TIA568 Standard.

Power interface adopts standard DC 5.5-2.1 connector.

4.4 Interface Box Connection

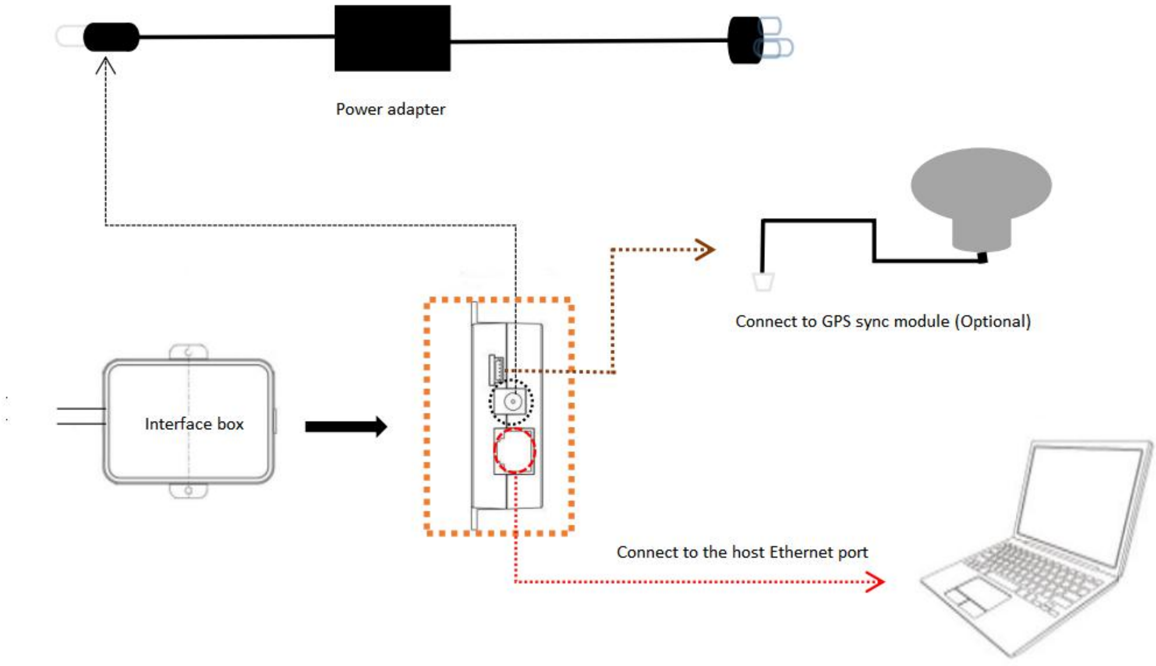


Figure 6: Interface Box connection diagram.

5 Communications Protocols

RS-LiDAR-16 adopts UDP protocol and communicates with computer through 100Mbps Ethernet. There two different kinds of UDP output packets: MSOP packets and DIFOP packets. The UDP protocol packet in this manual is of 1290 byte long, and consists of a 1248-bytes- payload and a 42-byte header. The IP address and port number of RS-LiDAR-16 is set in the factory as shown in the Table 2, but can be changed by the user as needed.

Table 2: The IP Address and Port Number Set at the Factory.

	IP Address	MSOP Port No.	DIFOP Port No.
RS-LiDAR-16	192.168.1.200	6699	7788
Computer	192.168.1.102		

The default MAC Address of each RS-LiDAR-16 is set in the factory. The MAC Address can be changed as needed.

To establish communication between a sensor and a computer, the IP address of the computer should be set at the same network segment of that of the sensor. By default: 192.168.1.X (X can be taken by a value from 1~254), subnet mask: 255.255.255.0. In case of uncertainty about the internet setting of the sensor, please connect the sensor to the computer, and parse packet to get the IP and port through Wireshark.

RS-LiDAR-16 adopts 3 kinds of communications protocols to establish communication with the computer:

- MSOP (Main Data Stream Output Protocol). Distance, azimuth and reflectivity data collected by the sensor are packed and output to computer.
- DIFOP (Device Information Output Protocol). Monitor the current configuration information of the sensor.
- UCWP (User Configuration Write Protocol). User can modify some parameters of the sensor as needed.

Table 3: Protocols Adopted by RS-LiDAR-16.

Protocol	Abbreviation	Function	Type	Size	Interval
Main Data Stream Output Protocol	MSOP	Scan Data Output	UDP	1248byte	~1.33 ms
Device Information Output Protocol	DIFOP	Device Information Output	UDP	1248byte	~100 ms
User Configuration Write Protocol	UCWP	Sensor Parameters Setting	UDP	1248byte	INF

Note： The following section describes and defines the valid payload (1248 byte) of the UDP protocol packet.

5.1 MSOP

I/O type: device output data, computer parse data.

Default port number is 6699.

MSOP outputs data information of the 3D environment in packets. Each MSOP packet is 1248 bytes long and consists of reported distance, calibrated reflectivity values, azimuth values and a time stamp.

Each RS-LiDAR-16 MSOP packet payload is 1248 byte long and consists of a 42-byte header and a 1200-byte data field containing twelve blocks of 100-byte data records and a 6-byte tail.

The basic data structure of a MSOP packet for single return is as shown in Figure 7.

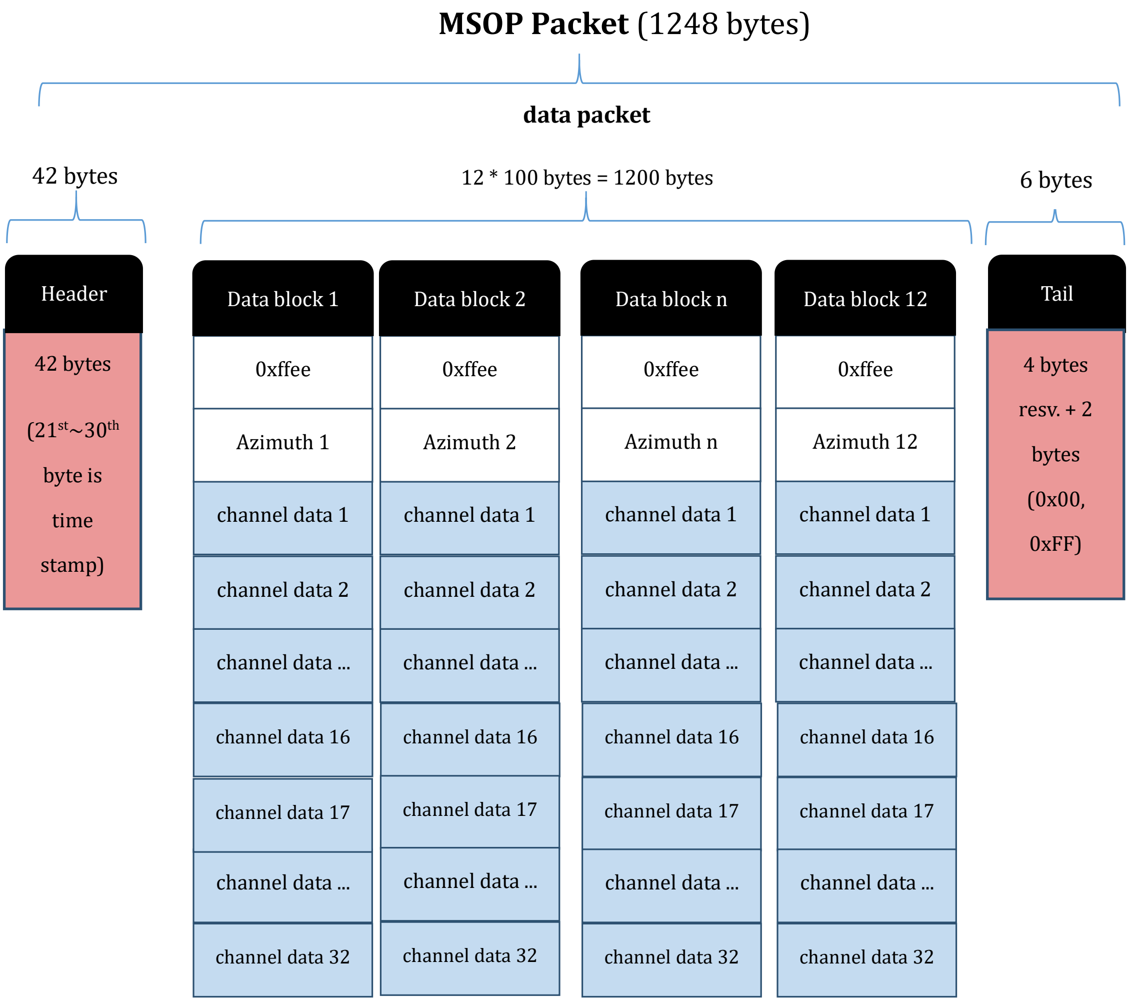


Figure 7: Single Return MSOP Packet.

The basic data structure of a MSOP packet for dual return is as shown in Figure 8.

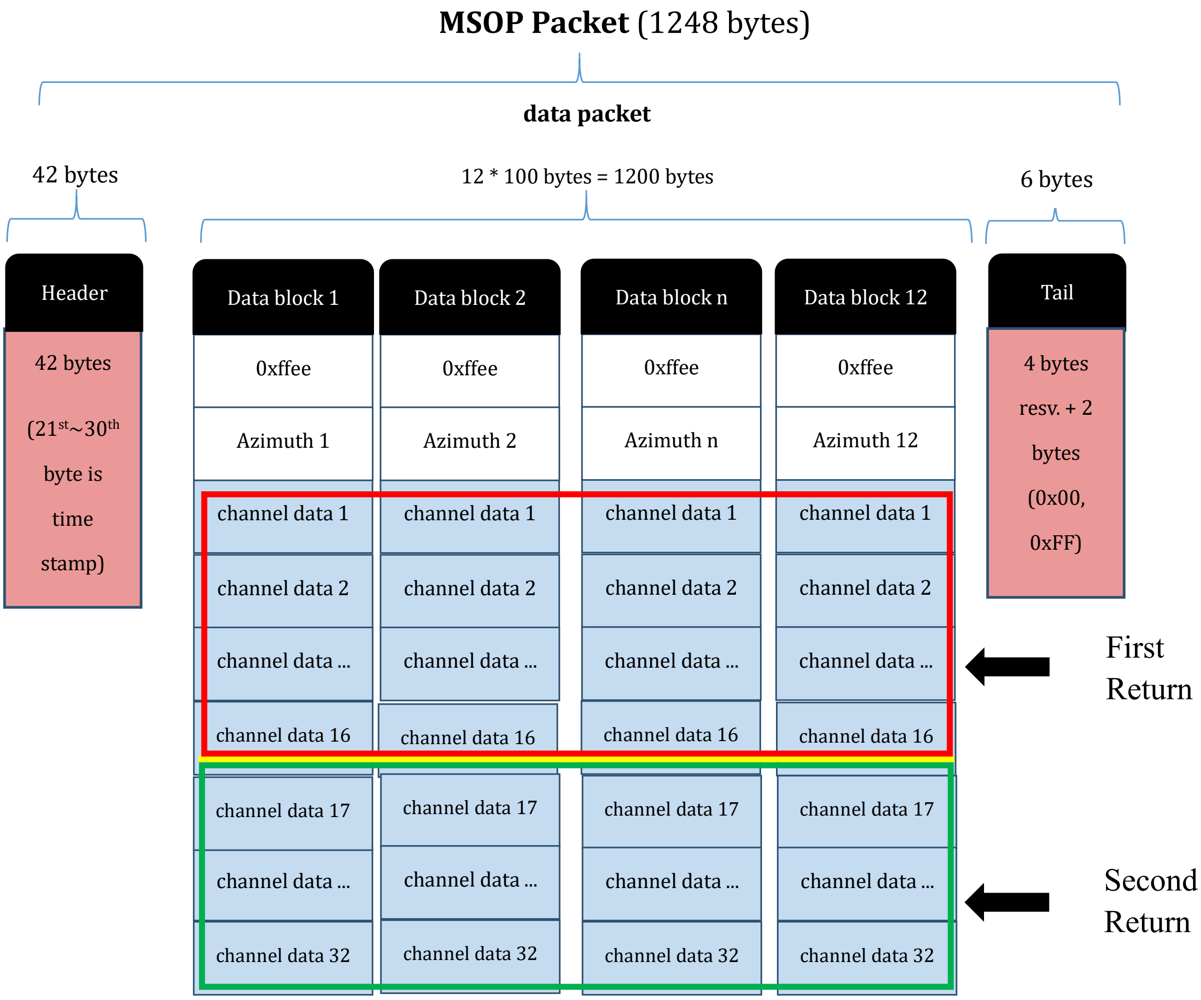


Figure 8: Dual Return MSOP Packet Definition Diagram.

5.1.1 Header

The 42-byte header marks the beginning of data blocks. In the 42-byte data header, the first 8 bytes are for header identification, the 21st. to 30th. byte records time stamp, the 31st byte represents the LiDAR model, and the rest bytes are reserved for future updates.

The first 8 bytes of the header is defined as 0x55,0xAA,0x05,0x0A,0x5A,0xA5,0x50,0xA0.

Time stamp with a resolution of 1 μs records the system time. Please refer to the definition of time in Appendix B.10 and Table 8 in part 3 of this section. The 31st byte LiDAR model is described as below:

Table 4: LiDAR Model Flag.

LiDAR Model (1 byte)	
0x01	RS-LiDAR-16
0x02	RS-LiDAR-32

5.1.2 Data Field

Data field comprises data blocks that contain valid measurement data. Each data filed contains 12 blocks. Each block is 100-byte long and is a complete measurement data set. Each data block begins with a 2-byte start identifier “0xffee”, then a two-byte azimuth value (rotational angle). Each azimuth value records 32 sets of channel data reported by the 16 laser channels for two sequence. (Please see chapter 9 for the relationship between channel sequence and vertical angel.)

5.1.2.1 Azimuth Value

The reported azimuth is associated with the first laser firing in each sequence of 16 laser firings. The Azimuth Value is recorded by the encoder. The zero position on the encoder indicates the zero degree of azimuth value on RS-LiDAR-16. In one data block, there are 32 sets of laser data indicating two sequence of the 16 laser firings, however only every-other encoder angle is reported for alternate firing sequences. So under single return mode user can choose to interpolate that unreported encoder stamp (Refer to 5.1.2.2). The resolution of Azimuth is 0.01°.

For example, in Figure 10, the azimuth value is calculated through the following steps:

Get azimuth values: 0x00，0x44

Combine to a 16 bit, unsigned integer: 0x0044

Convert to decimal: 68

Divided by 100

Result: 0.68°

Hence the firing angle is 0.68°

Note*: the position of 0° on sensor is the Y axis positive direction in Figure 14.*

5.1.2.2 Azimuth Value Interpolation

Because the RS-LIDAR-16 reports the azimuth value for every-other firing sequence, it’s helpful to interpolate the un-reported azimuth when the LiDAR works under single return. There are several ways to interpolate the un-reported azimuth, but the one given below is simple and straight forward.

Consider a single data packet. The time between the first firing of the first sequence of sixteen firings (Data Block 1) and the first firing of the third sequence of sixteen laser firings (Data Block 2) is ~100.0 μs. If you assume the rotation speed over that short interval is constant, you can assume the azimuth of the (N+1) set of sixteen laser firings is halfway between the azimuth reported with the Nth set of 16 laser firings and the azimuth reported with the (N+2) set of laser firings.

Below is pseudo-code that performs the interpolation. The code checks to see if the azimuth rolled over from 359.99° to 0° between firing sequence N and N+2.

In the example below, N=1.

// First, adjust for a rollover from 359.99° to 0°

If (Azimuth[3] < Azimuth[1])

Then Azimuth[3]:= Azimuth[3]+360;

Endif;

// Perform the interpolation

Azimuth[2]:=Azimuth[1]+((Azimuth[3]-Azimuth[1])/2);

// Correct for any rollover over from 359.99° to 0°

If (Azimuth[2]>360)

Then Azimuth[2]:= Azimuth[2]-360;

Endif

5.1.2.3 Channel Data

Channel data contains 3 bytes, with the upper 2 bytes store distance information, and the lower 1 byte contains reflectivity data. The structure of channel data is as shown in Table 5.

Table 5: Channel Data.

Channel Data N (3 bytes)		
2 bytes Distance		1 byte Reflectivity
Distance1 [15:8]	Distance2 [7:0]	Reflectivity

The 2-byte distance data is set in centimeter. The resolution is different between 1 cm and 0.5 cm due to the different LiDAR firmware.

Reflectivity data records relative reflectivity (more definition on reflectivity, please refer to description on calibrated reflectivity in Section 9 of this manual). Reflectivity data reveals the reflectivity performance of the system in real measurement environments, it can be used in distinguishing different materials.

The following shows how to parse channel data.

In the case of Figure 10/11, the distance information is calculated by:

Get distance values: 0x06 ,0x42

Combine distance bytes to a 2-byte, unsigned integer: 0x0642

Convert to decimal: 1602

According to the distance resolution difference, it can be calculated:

1cm resolution result: 16.02 meters; 0.5cm resolution result: 8.01 meters;

Hence the distance measured is 16.02m.

5.1.3 Tail

The tail is 6 bytes long, with 4 bytes unused and reserved for information, and the other 2 bytes as: 0x00, 0xFF.

5.1.4 Demonstration Data

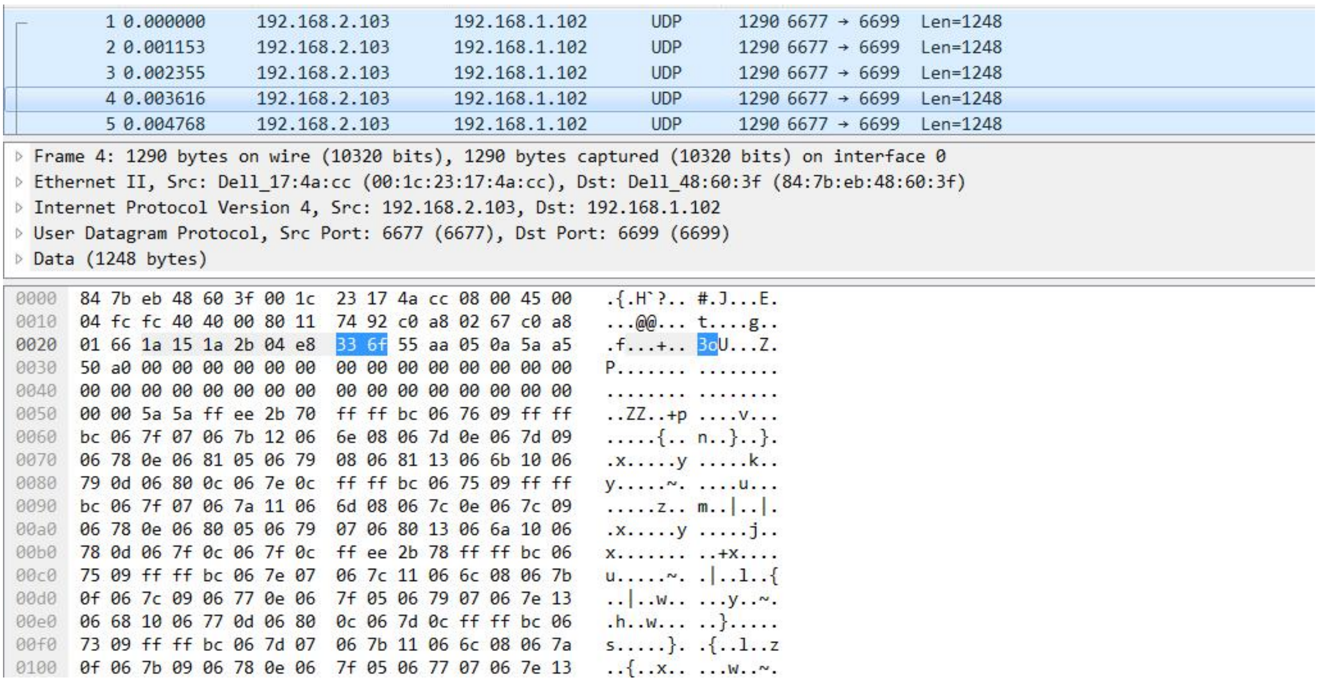


Figure 9: MSOP Packet Display.

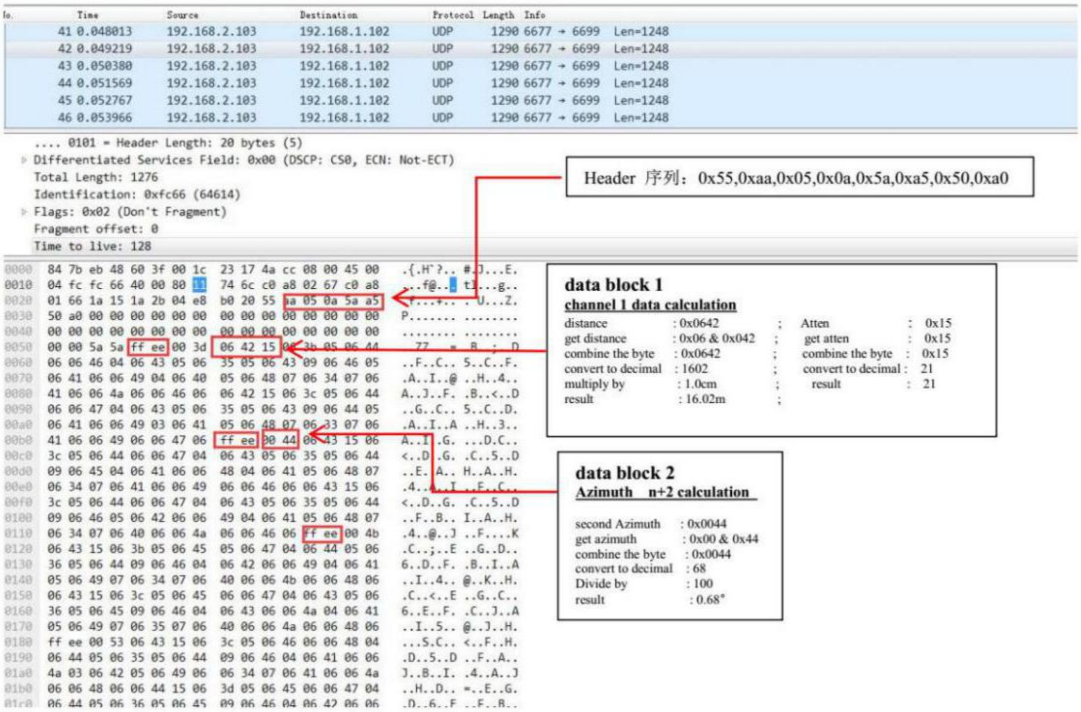


Figure 10: 1 cm Resolution Data Block Display.

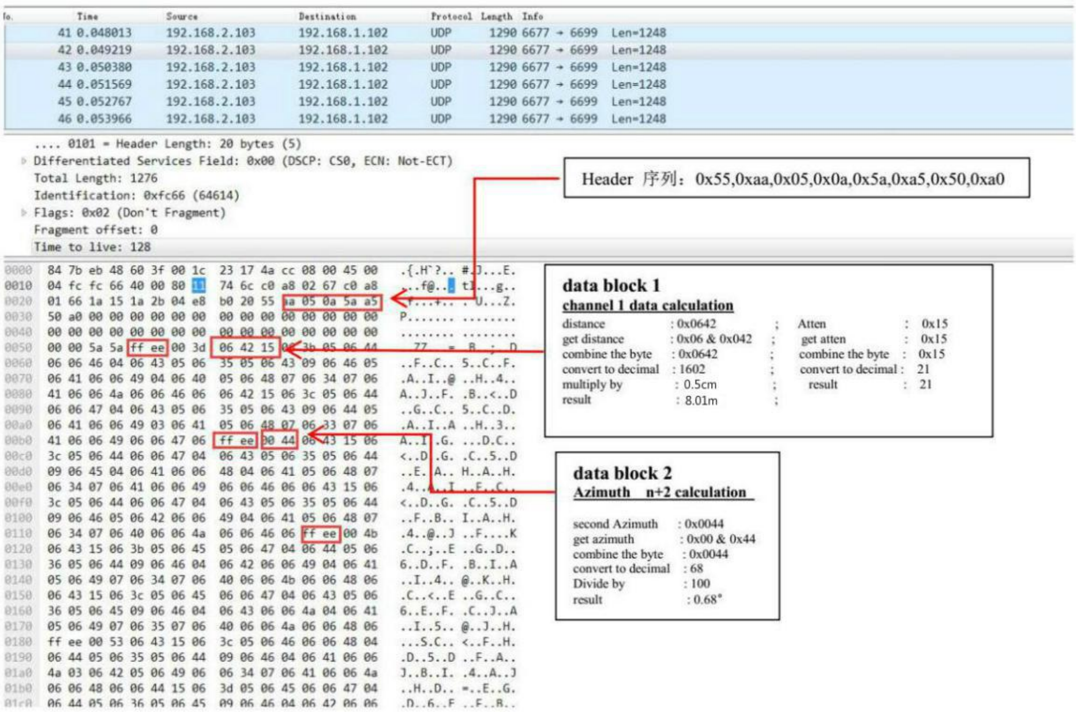


Figure 11: 0.5 cm Resolution Data Block Display.

5.2 DIFOP

I/O type：device output, computer read.

Default port number is 7788.

DIFOP is a protocol that reports and outputs only device information including the device serial number, firmware version, driver compatibility, internet setting, calibration data, electrical machine setting and operation status, fault detection information to users. It is a viewer for users to get comprehensive details about the device.

Each DIFOP packet is 1248 byte long, and comprises an 8-byte Header, a 1238-byte data field, and a 2-byte Tail.

The structure of DIFOP is as shown in Table 6.

Table 6: Data Format of DIFOP Packet.

	No.	Information	Offset	Length(byte)
Header	0	DIFOP header	0	8
Data	1	Motor rotation speed (MOT_SPD)	8	2
	2	Ethernet (ETH)	10	22
	3	FOV setting	32	4
	4	Corrected static base (COR_STATIC_BASE)	36	2
	5	Motor phase lock (MOT_PHASE)	38	2
	6	Top board firmware version (TOP_FRM)	40	5
	7	Bottom board firmware version (BOT_FRM)	45	5
	8	Corrected intensity curves coefficient	50	240
	9	Intensity scale	290	1
	10	Intensity Mode	291	1
	11	Serial number (SN)	292	6
	12	Zero angle offset	298	2
	13	Return mode	300	1
	14	Upper computer compatibility	301	2
	15	UTC time (UTC_TIME)	303	10

	16	Operation status (STATUS)	313	18
	17	Reserved	331	11
	18	Fault diagnosis (FALT_DIGS)	342	40
	19	GPRMC	382	86
	20	Corrected static (COR_STATIC)	468	697
	21	Corrected vertical angle (COR_VERT_ANG)	1165	48
	22	Reserved	1213	33
Tail	23	Tail	1246	2

Note: The Header (the DIFOP identifier) in the table above is 0xA5, 0xFF, 0x00, 0x5A, 0x11, 0x11, 0x55, 0x55, among which the first 4 byte 0xA5,0xFF,0x00,0x5A is the sequence to identify the packet.

The tail is 0x0F,0xF0.

For definition of information registers as well as their usage, please check more details in Appendix B of this manual.

5.3 UCWP

I/O type: computer writes into the device.

Function: user can reconfigure Ethernet connection, time and some parameters of the device.

Each UCWP Packet is 1248 byte long, and is comprised of an 8-byte Header and a 40-byte data field.

The UCWP packet structure is as shown below:

Table 7: Data Format of UCWP Packet.

	No.	Info	Offset	Length(byte)
Header	0	UCWP header	0	8
Data	1	Motor rotation speed	8	2
	2	Ethernet	10	22
	3	FOV setting	32	4
	4	Time	36	10
	5	Motor phase lock	46	2

Note: The Header (UCWP identifier) in the table above is 0xAA, 0x00, 0xFF, 0x11, 0x22, 0x22, 0xAA, 0xAA, among which, the first 4 bytes 0xAA, 0x00, 0xFF, 0x11 forms the sequence to identify the packet.

Statement: RS-LiDAR-16 doesn't RTC system to support operation while power is off. In the case of no GPS or GPS signal, it is imperative to write time into the device through a computer, or it will use a default system time for clock.

Refer to Appendix B of this manual for details on Ethernet, Time, Motor Rotation Speed and Motor Phase Lock. Below is an example to configure the RS-LIDAR-16:

LiDAR IP: 192.168.1.105,

Destination PC IP: 192.168.1.225,

MAC_ADDR: 001C23174ACC

MSOP port: 6688

DIFOP port: 8899

FOV starting angle: 0°

FOV end angle: 120°

Time: 09:45:30:100:200, March 10, 2017

Rotation speed: 600rpm

Motor phase lock: 90 degree

User can reset the above information by following the example in Table 8.

Table 8: Setting of UCWP Packet.

Information	Content	Setting	Length(byte)
Header		0xAA,0x00,0xFF,0x11, 0x22,0x22,0xAA,0xAA	8
Rotate Speed	1200rpm	0x04, 0xB0	2
LiDAR IP (LIDAR_IP)	192.168.1.105	0xC0, 0xA8 0x01, 0x69	4
Destination PC IP (DEST_PC_IP)	192.168.1.225	0xC0, 0xA8 0x01, 0xE1	4
Device MAC Address(MAC_ADDR)	001C23174ACC	0x00,0x1C,0x23, 0x17,0x4A,0xCC	6
MSOP Port(port1)	6688	0x1A20	2
MSOP Port(port2)	6688	0x1A20	2

DIFOP Port(port3)	8899	0x22C3	2
DIFOP Port(port4)	8899	0x22C3	2
FOV starting angle	0	0x0000	2
FOV end angle	12000	0x2EE0	2
UTC_TIME	Year:2017 Month:3 Day:10 Hour:9 Minute:45 Second:30 Millisecond: 100 Microsecond: 200	0x11 0x03 0x0A 0x09 0x2D 0x1E 0x00,0x64 0x00,0xC8	10
Motor Phase Lock	90	0x005A	2

While setting the device and computer according to this protocol, it is imperative to set all the information listed in the table above. Addressing or writing in with part of the information will lead to invalid setting. The function refreshes the moment the correspondent parameter is changed, but the network parameters only take effect when the next initialization of device is started.

RSVIEW provides the configuration UI, so we suggest to use RSVIEW to configure the RS-LiDAE-16. When performing the parameter writing process, please keep the power connection for LiDAR and make sure the parameter writing is done when we want to power off the LiDAR, otherwise there is a risk of parameter configuring error.

6 GPS Synchronization

RS-LiDAR-16 supports external GPS receiver connections. With GPS connections, we can synchronize the RS-LiDAR-16 system time and pack the GPRMC message into DIFOP packets.

6.1 GPS Synchronization Theory

The GPS receiver keeps generating synchronization Pulse Per Second (PPS) signal and GPRMC message and send them to the sensor. The pulse width of the PPS should between 20ms to 200ms, and the GPRMC message should be received within 500ms after the PPS signal is generated.

6.2 GPS Usage

There are two different level protocols for GPS_REC PINs:

3.3V TTL level standard and RS232 level standard respectively.

It can be distinguished by checking the firmware version which is shown in Appendix C RS-View of this user manual, Figure C-14. If version No. begins with 08, it is TTL protocol. If version No. begins with 09, it is RS232 protocol. The GPS interface on the Interface BOX is SH1.0-6P female connector, the PIN definition is as shown in Figure 4. There are two main differences between the two protocols, which are shown as below:

TTL level PIN definition: PIN GPS REC receives the data that is 3.3 V TTL standard from GPS module serial port.

PIN GPS PULSE receives the PPS from GPS module.

RS232 PIN definition:

PIN GPS REC receives the data that is R232 level standard from the GPS module serial port;

PIN GPS PULSE receives the PPS from GPS module, and the level requirement is 3.0V~15.0V;

If the GPS output you are using is RS232 serial protocol while the level of the LiDAR receiver is TTL, then you need to purchase a module which converts RS232 level to TTL level. For one example, the wiring diagram and definition are in Figure 12 as follows:

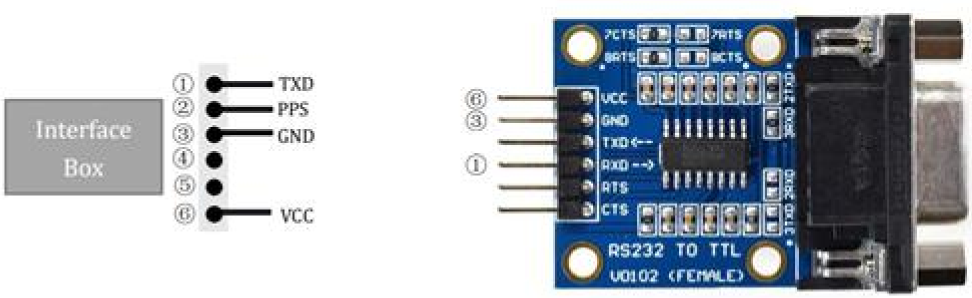


Figure 12: RS232 to TTL Level Conversion Module.

PIN +5 V can supply the power for GPS module. (Please do not connect the GPS into the +5 V PIN if the GPS is 3.3 V power supply. Also please do not input the power into the +5 V PIN because the PIN is an output.)

PIN GND provide the ground connection for GPS module.

The GPS module should set to 9600 bps baud rate, 8-bit data bit, no parity and 1 stop bit. RS-LiDAR-16 only read the GPRMC message from GPS module., the GPSMRC message format is shown as below:

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

<1> UTC time

<2> validity - A-ok, V-invalid

<3> Latitude

<4> North/South

<5> Longitude

<6> East/West

<7> Ground Speed

<8> True course

<9> UTC date

<10> Variation

<11> East/West

<12> Mode (A/D/E/N=)

*hh checksum from $ to *

Different GPS module may send out different length GPRMC message, the RS-LiDAR-16 reserve 86byte space for GPRMC message, so it can be compatible with the majority GPS module in the market.

7 Key Features

7.1 Return Mode

7.1.1 Return Mode Principle

RS-LiDAR-16 supports multiple return modes: Strongest return, Last return and Dual return. When set to dual return mode, the details of the target will be enhanced, and the number of points is twice than that of a single return.

Due to the divergence of the beam, it is possible to generate multiple laser returns with one laser emission. When the laser pulse is emitted, its light spot gradually becomes larger. Suppose a light spot is large enough to shot multiple targets and produce multiple returns. Generally, the farther away the target is, the weaker it will be at the receiver, while the retro reflective surface may be the opposite.

RS-LiDAR-16 analyzes the received multiple return values and outputs the strongest, last or simultaneous output of these two return values depending on the setting. If set to the strongest return mode, only the strongest return value is output. Similarly, if the setting is the last return mode, only the last return value is output; if set to double return mode, the strongest and last return information is output simultaneously.

Note: Only when the distance between two objects is greater than 1 meter, the LiDAR could distinguish these two returns.

7.1.2 The Strongest Return

When the LiDAR beam hits only one object, there is only the strongest return at this time.

7.1.3 Strongest, Last and Dual Returns

When the laser pulse hits two objects at different distances, there will be two return wave, then it will lead two situations:

(1) When the strongest return is not the last return, return the strongest and last return;

(2) When the strongest return is also the last return, return the strongest return and the second strongest return;

7.1.4 Return Mode Flag

The factory default setting for RS-LiDAR-16 is the Strongest Return mode. If you need to change the settings, please refer to Figure C-14 in Appendix C of this user manual. The 300th Byte in the DIFOP is the flag of the return mode, which corresponds to the following:

Table 9: Return Mode and Flag Byte Comparison Table.

Flag Byte	Return Mode
00	Dual Returns
01	Strongest Return
02	Last Return

7.2 Phase Lock

When using multiple RS-LiDAR-16 sensors in proximity to one another, users may observe interference between them due to one sensor picking up a reflection intended for another. To minimize this interference, RS-LiDAR-16 provides a phase-locking feature that enables the user to control where the lase firings overlap.

The Phase Lock feature can be used to synchronize the relative rotational position of multiple sensors based on the PPS signal and relative orientation. To operate correctly, the PPS signal must be present and locked. Phase locking works by offsetting the rising edge of the PPS signal.

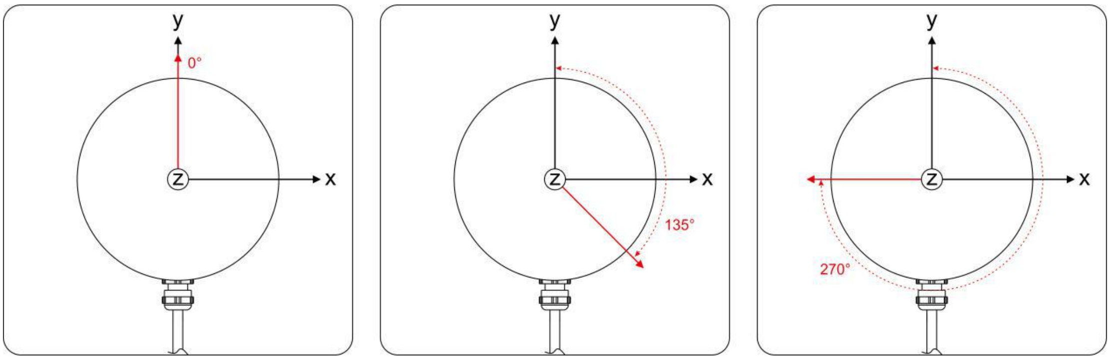


Figure 13: Phase Offset 0°/135°/270°.

The red arrows in Figure 13 above indicate the firing direction of the sensor's laser the moment it receives the rising edge of the PPS signal.

In the **Tools > RS-LiDAR Information** of RSVIEW, we can set the Phase Lock angle from 0 to 359.

The phase lock function requires the rotate speed to be set up at 600 or 1200 rpm.

8 Point Cloud

8.1 Coordinate Mapping

RS-LiDAR-16 exports data packet that contains azimuth value and distance data. But to present a 3-dimensional point cloud effect, a transformation of the azimuth value and distance data into x, y, z coordinates in accordance to Cartesian Coordinate System is necessary. The function of how to transfer the information is as shown below:

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

Here r is the reported distance, ω is the vertical/elevation angle of the laser(which is fixed and is given by the Laser ID), and α is the horizontal angle/azimuth reported at the beginning of every other firing sequence. x, y, z values are the projection of the polar coordinates on the XYZ Cartesian Coordinate System.

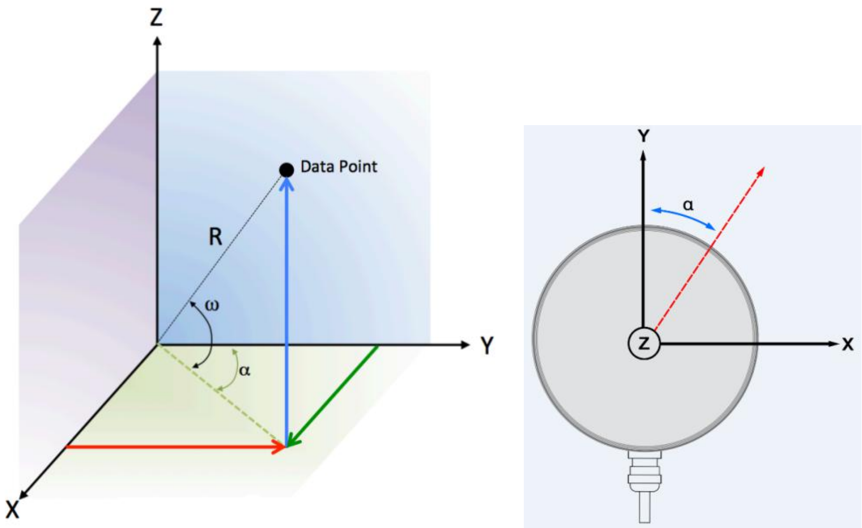


Figure 14: Coordinate Mapping.

Note 1： *In the RS-LiDAR-16 ROS package, we use a coordinate transformation by default to compatible with the ROS right-handed coordinate system: ROS-X axis is the Y axis as Figure 14, while ROS-Y axis is -X axis as Figure 14, Z axis keep the same.*

Note 2: *The origin of the LiDAR coordinate is defined at the center of the LiDAR structure, with 39 mm high to the bottom of the LiDAR.*

8.2 Point Cloud Presentation

In a circular arena, as the RS-LiDAR-16 rotates, the scanning path of the 16 laser beams plots 16 conical scanning surfaces with 8 face upward and 8 face downward, and the point cloud produced are the section line between these conical surfaces and the floor which are circles. While in non-circular environments, the point cloud produced are the section lines of the conical surfaces and the surface of objects. Therefore, in a rectangular environment, the section lines of the conical surfaces and the rectangular planes are hyperbolas as shown in Figure 15.

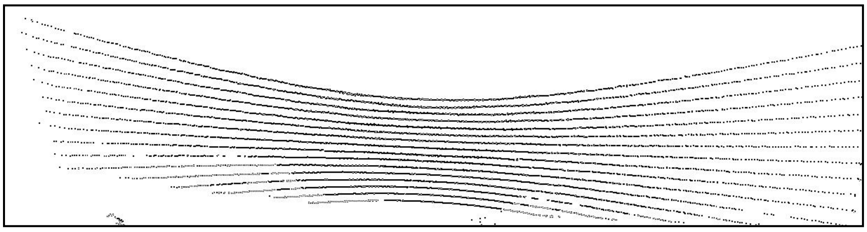


Figure 15:Contour lines plotted on X, Z coordinates.

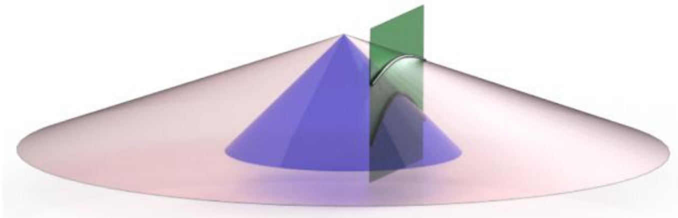


Figure 16: RS-LiDAR-16 Scanning Illustration.

The hyperbolas contour lines phenomenon can also be explained by transforming polar coordinates into orthogonal coordinates. As shown in Figure 17, we deduced the function of a hyperbolas $\frac{z^2}{(y\tan(\omega))^2} - \frac{x^2}{y^2} = 1$. When y and ω are definite values, it indicates a hyperbola with focus on z coordinate. When y is a definite value, as α gains in value, the asymptote slope and eccentricity will decline thereof, which resulted a more curved hyperbola. On the contrary, as α loses in value, a more flat hyperbola is resulted. When ω is a definite value, as y gains in value, the asymptote of the same angle presents same slope, the value of y determines the width between scanning contours.

$$x = r\cos(\omega)\cos(\alpha);$$
$$y = r\cos(\omega)\sin(\alpha);$$
$$z = r\sin(\omega);$$

↓

$$x^2 + y^2 = z^2\cos^2(\omega)/\sin^2(\omega)$$

↓

$$\frac{z^2}{(y\tan(\omega))^2} - \frac{x^2}{y^2} = 1$$

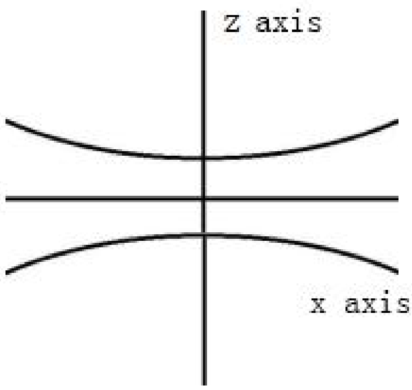


Figure 17: Hyperbolic Function.

9 Laser Channels and Vertical Angles

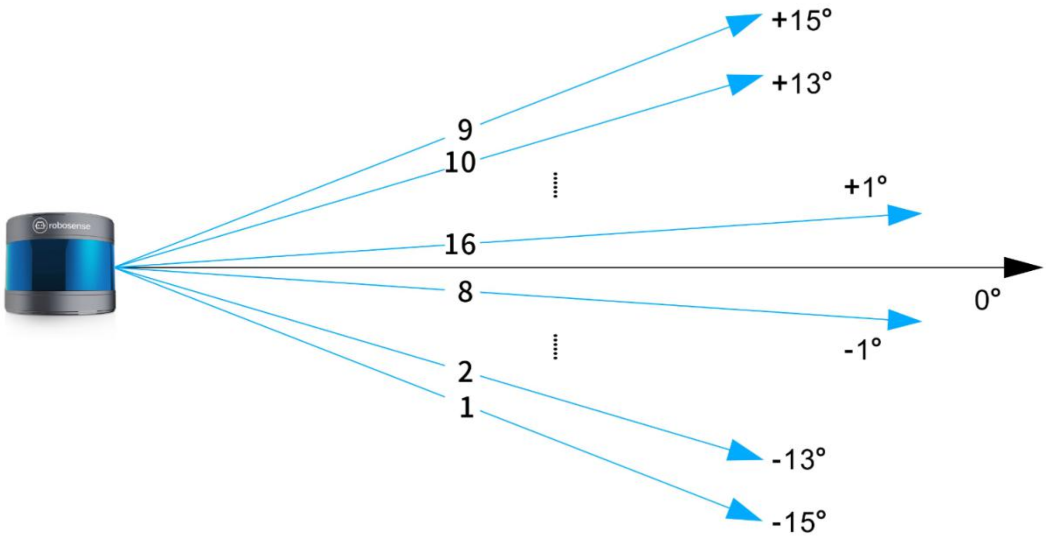


Figure 18:RS-LiDAR-16 Laser Channels and Vertical Angles.

RS-LiDAR-16 has a vertical field of view of -15°to +15°with an interval of 2°. The 16 laser heads also called as 16 channels. The laser channels and their designated vertical angles are as shown in the Table 10.

Table 10: Laser Channel Number and Their Designated Vertical Angle.

Laser Channel No.	Ideal Vertical Angle
1	-15
2	-13
3	-11
4	-9
5	-7
6	-5
7	-3
8	-1
9	+15
10	+13
11	+11

12	+9
13	+7
14	+5
15	+3
16	+1

Every sequence of 16 laser firings consumes 55.5 μs.

10 Calibrated Reflectivity

RS-LiDAR-16 produces calibrated reflectivity data of objects. Reflectivity of object is largely determined by the property of objects. Reflectivity therefore is an important information for LiDAR to distinguish objects.

RS-LiDAR-16 reports reflectivity values from 0 to 255 with 255 being the reported reflectivity for an ideal reflector. Diffuse reflection reports values from 0 to 100, with the weakest reflectivity reported from black objects and strongest reflectivity reported from white object. Retro- reflector reports values from 101 to 255.

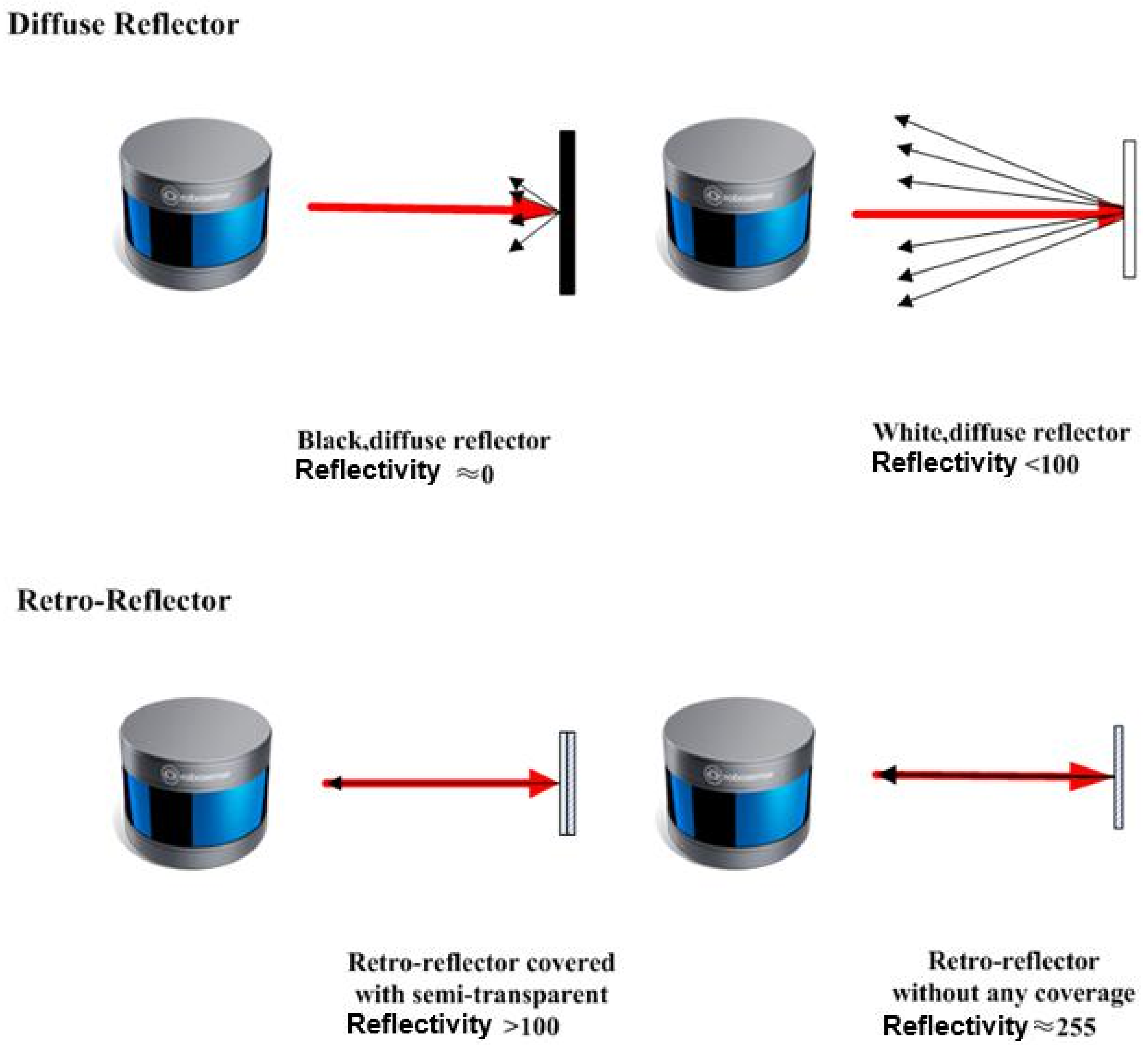


Figure 19: Calibration of Reflectivity.

To calculate each point intensity, we need use the intensity value from MSOP packet and the values from the calibrated reflectivity file. The calibrated reflectivity file can be found from the U disk (path:

configuration_data/curves.csv). The calculate code is suggested to refer to the function calibrateIntensity( ) in rawdata.cc from RS-LiDAR-16 ROS package.

Note 1: *Because of the firmware upgrade, the calculation of the intensity in the calibrateIntensity() function has been adjusted for several times, and the new code is backward compatible with the earlier firmware. There are three modes to calculate the reflectivity. The first two need to convert the intensity byte output by the LiDAR to obtain the final result. V4.0 used mode 3 method directly uses the intensity output by the LiDAR, and the conversion and calculation are done inside the LiDAR.*

Note 2: *For LiDAR produced after the date of 20.11.2018, for mode 3, LiDAR output directly the intensity of reflectivity, calculation is accomplished inside of LiDAR.*

11 Troubleshooting

This section provides detail on how to troubleshoot your sensor.

Problem	Resolution
Interface BOX red LED doesn't light or blink	● Verify the power connection and polarity ● Verify the power supply satisfy the requirement (at least 2A @ 12V)
Interface BOX red LED lights on but green LED doesn't light or blink	● Verify the connection between Interface BOX and LiDAR is solid.
Rotor doesn't spin	● Verify the Interface BOX LEDs is okay ● Verify the connection between Interface BOX and LiDAR is solid.
Reboot at the boot time	● Verify the power connection and polarity ● Verify the power supply satisfy the requirement (at least 2A @ 12V) ● Check if the LiDAR mounting plane is level or if the LiDAR bottom fixing screws are too tight.
Unit spin but no data	● Verify network wiring is functional. ● Verify receiving computer's network settings. ● Verify packet output using another application (e.g. Wireshark) ● Verify no security software is installed which may block Ethernet broadcasts. ● Verify input voltage and current draw are in proper ranges
Can see data in Wireshark but not RSVIEW	● Check the no firewall is active on receiving computer. ● Check the receiving computer's IP address is the same as LiDAR destination IP address. ● Check the RSVIEW Data Port setting. ● Check the RSVIEW installation path and LiDAR configuration files path both do not contain any Chinese characters. ● Check if the wireshark receive the MSOP packets.
Data dropouts	● This is nearly always an issue with the network and/or user computer. ● Check the following: ● Is there excessive traffic and/or collisions on network?

	● Are excessive broadcast packets from another service being received by the sensor? This can slow the sensor down ● Is the computer fast enough to keep up with the packet flow coming from the sensor? ● Remove all network devices and test with a computer directly connected to the sensor.
GPS not synchronizing	● Check baud rate is 9600 and serial port set to 8N1 (8 bits, no parity, 1 stop bit). ● Check the signal level is 3.3V TTL or RS232 level ● Check electrical continuity of PPS and serial wiring ● Check incorrect construction of NMEA sentence ● Check the GPS and Interface BOX are connected to the same GND ● Check the GPS receive the valid data
No data via router	● Close the DHCP function in router or set the Sensor IP in router configuration
Sensor point cloud data distortion	● Check the configuration files is right
A blank region rotate in the cloud data when using ROS driver	● This is the normal phenomenon as the ROS driver use fixed packets quantity to divide display frame. The blank region data will output in the next frame.
Point cloud data to be a radial	● If the computer is windows 10 OS, then run the RSVIEW with windows 7 OS compatible mode.

Appendix A ▪ Point Time Calculate

In a MSOP packet, there are 12 blocks, each block has two sequence for the whole 16 laser firings, so in a MSOP packet, there are 24 groups for the whole 16 laser firings. All sixteen lasers are fired and recharged every 55.5μs. The cycle time between firing is 2.8μs. There are 16 firings (16 x 2.8μs = 44.8 μs) followed by a short period of 10.7μs. Therefore, the timing cycle to fire and recharge all 16 lasers is given by ((16 x 2.8μs) + (1 x 10.7μs)) = 55.5μs.

Set the channel number data_index is 1-16, firing sequences is 1-24. Because the time stamp is the time of the first data point in the packet, you need to calculate a time offset for each data point and then add this offset to the time stamp.

Time offset is:

$$Time\_offset = 55.5\ \mu s * (sequence\_index - 1) + 2.8\ \mu s * (data\_index - 1)$$

To calculate the exact point time, add the TimeOffset to the timestamp:

$$Exact\_point\_time = Timestamp + Time\_offset$$

Table A - 1: Time Offset for Each Channel in MSOP Packet.

	Channel ID	Data Block											
		1	2	3	4	5	6	7	8	9	10	11	12
First Firing	1	0	111	222	333	444	555	666	777	888	999	1110	1221
	2	2.8	113.8	224.8	335.8	446.8	557.8	668.8	779.8	890.8	1001.8	1112.8	1223.8
	3	5.6	116.6	227.6	338.6	449.6	560.6	671.6	782.6	893.6	1004.6	1115.6	1226.6
	4	8.4	119.4	230.4	341.4	452.4	563.4	674.4	785.4	896.4	1007.4	1118.4	1229.4
	5	11.2	122.2	233.2	344.2	455.2	566.2	677.2	788.2	899.2	1010.2	1121.2	1232.2
	6	14	125	236	347	458	569	680	791	902	1013	1124	1235
	7	16.8	127.8	238.8	349.8	460.8	571.8	682.8	793.8	904.8	1015.8	1126.8	1237.8
	8	19.6	130.6	241.6	352.6	463.6	574.6	685.6	796.6	907.6	1018.6	1129.6	1240.6
	9	22.4	133.4	244.4	355.4	466.4	577.4	688.4	799.4	910.4	1021.4	1132.4	1243.4
	10	25.2	136.2	247.2	358.2	469.2	580.2	691.2	802.2	913.2	1024.2	1135.2	1246.2
	11	28	139	250	361	472	583	694	805	916	1027	1138	1249
	12	30.8	141.8	252.8	363.8	474.8	585.8	696.8	807.8	918.8	1029.8	1140.8	1251.8
	13	33.6	144.6	255.6	366.6	477.6	588.6	699.6	810.6	921.6	1032.6	1143.6	1254.6
	14	36.4	147.4	258.4	369.4	480.4	591.4	702.4	813.4	924.4	1035.4	1146.4	1257.4
	15	39.2	150.2	261.2	372.2	483.2	594.2	705.2	816.2	927.2	1038.2	1149.2	1260.2
	16	42	153	264	375	486	597	708	819	930	1041	1152	1263
Second Firing	1	55.5	166.5	277.5	388.5	499.5	610.5	721.5	832.5	943.5	1054.5	1165.5	1276.5
	2	58.3	169.3	280.3	391.3	502.3	613.3	724.3	835.3	946.3	1057.3	1168.3	1279.3
	3	61.1	172.1	283.1	394.1	505.1	616.1	727.1	838.1	949.1	1060.1	1171.1	1282.1
	4	63.9	174.9	285.9	396.9	507.9	618.9	729.9	840.9	951.9	1062.9	1173.9	1284.9
	5	66.7	177.7	288.7	399.7	510.7	621.7	732.7	843.7	954.7	1065.7	1176.7	1287.7
	6	69.5	180.5	291.5	402.5	513.5	624.5	735.5	846.5	957.5	1068.5	1179.5	1290.5
	7	72.3	183.3	294.3	405.3	516.3	627.3	738.3	849.3	960.3	1071.3	1182.3	1293.3
	8	75.1	186.1	297.1	408.1	519.1	630.1	741.1	852.1	963.1	1074.1	1185.1	1296.1
	9	77.9	188.9	299.9	410.9	521.9	632.9	743.9	854.9	965.9	1076.9	1187.9	1298.9
	10	80.7	191.7	302.7	413.7	524.7	635.7	746.7	857.7	968.7	1079.7	1190.7	1301.7
	11	83.5	194.5	305.5	416.5	527.5	638.5	749.5	860.5	971.5	1082.5	1193.5	1304.5
	12	86.3	197.3	308.3	419.3	530.3	641.3	752.3	863.3	974.3	1085.3	1196.3	1307.3
	13	89.1	200.1	311.1	422.1	533.1	644.1	755.1	866.1	977.1	1088.1	1199.1	1310.1
	14	91.9	202.9	313.9	424.9	535.9	646.9	757.9	868.9	979.9	1090.9	1201.9	1312.9
	15	94.7	205.7	316.7	427.7	538.7	649.7	760.7	871.7	982.7	1093.7	1204.7	1315.7
	16	97.5	208.5	319.5	430.5	541.5	652.5	763.5	874.5	985.5	1096.5	1207.5	1318.5

Appendix B ▪ Information Registers

Here are definitions and more details on information registers as mentioned in Section 5.

B.1 Motor(MOT_SPD)

MOT_SPD (2 bytes in total)		
Byte No.	byte1	byte2
Function	MOTOR	

Register description:

(1) This register is used to set the rotation direction and rotation speed.

(2) The data storage format adopts big endian format.

(3) Supported rotation speed:

(byte1==0x04) && (byte2==0xB0) speed 1200rpm, clockwise rotation;

(byte1==0x02) && (byte2==0x58) speed 600rpm, clockwise rotation;

(byte1==0x01) &&(byte2==0x2C) speed 300rpm, clockwise rotation;

If set with data other than the above described, the rotation speed of the motor is 0.

B.2 Ethernet(ETH)

ETH (22 bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	LIDAR_IP				DEST_PC_IP			
Byte No.	byte9	byte10	byte11	byte12	byte13	byte14	byte15	byte16
Function	MAC_ADDR						port1	
Byte No.	byte17	byte18	byte19	byte20	byte21	byte22		
Function	port2		port3		port4			

Register description:

(1) LIDAR_IP is the LiDAR source IP address. It takes 4 bytes.

(2) DEST_PC_IP is the destination PC IP address. It takes 4 bytes.

(3) MAC_ADDR is the LiDAR MAC Address.

(4) port1~port4 signals the number of ports. Port1 is MSOP Port Number of LiDAR for outputting packet and port2 is the destination PC Port Number for receiving MSOP packet. Port3 is DIFOP Port Number of LiDAR for outputting packet and port4 is the destination PC Port Number for receiving DIFOP packet. By default, Port1 and port2 are same, port3 and port4 are same.

B.3 FOV Setting (FOV SET)

FOV SET(4bytes in total)				
No.	byte1	byte2	byte3	byte4
Function	FOV_START		FOV_END	

Register Description: Set the horizontal angle range of the device for outputting valid data, FOV_START and FOV_END adjustment range 0~36000, corresponding angle 0~360°, the data storage format adopts big endian format. For example: the byte1 = 0x5d，byte2 = 0xc0，byte3 = 0x1f，byte4 = 0x40, so:

FOV_START = 93*256+192=24000

FOV_END = 31*256+64=8000

Indicates that the valid data output has a horizontal angle ranging from 240.00° to 80.00°.

***Note:** In all above calculation, bytes have been transformed to decimal.*

B.4 Motor Phase Offset (MOT_PHASE)

MOT_PHASE(2bytes in total)		
No.	byte1	byte2
Function	MOT_PHASE	

Register description: It can be used to adjust the phase offset of the motor with the PPS together. The value can be set from 0 to 360. The data storage format adopts big endian format. For example: the byte1=1, byte2=14, so the motor phase should be 1*256+14 = 270.

***Note:** In all above calculation, bytes have been transformed to decimal.*

B.5 Top Board Firmware (TOP_FRM)

TOP_FRM(5bytes in total)					
No.	byte1	byte2	Byte3	Byte4	Byte5
Function	TOP_FRM				

Register description：

If our top board firmware revision is T6R23V6_T6_A, then TOP_FRM will output 06 23 06 06 A0. In the output, the A represents release version Application, while the F represents factory version Factory.

B.6 Bottom Board Firmware (BOT_FRM)

BOT_FRM(5bytes in total)					
No.	byte1	byte2	Byte3	Byte4	Byte5
Function	BOT_FRM				

Register description：

If our top board firmware revision is B7R14V4_T1_F, then BOT_FRM will output 07 14 04 01 F0. In the output, the A represents release version Application, while the F represents factory version Factory.

B.7 Corrected Vertical Angle (COR_VERT_ANG)

COR_VERT_ANG(48 bytes in total)									
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8	Byte9
Function	Channel 1			Channel 2			Channel 3		
Byte No.	byte10	Byte11	Byte12	Byte13	Byte14	Byte15	Byte16	Byte17	Byte18
Function	Channel 4			Channel 5			Channel 6		
Byte No.	byte19	byte20	Byte21	Byte22	Byte23	Byte24	Byte25	Byte26	Byte27
Function	Channel 7			Channel 8			Channel 9		
Byte No.	Byte28	byte29	byte30	Byte31	Byte32	Byte33	Byte34	Byte35	Byte36
Function	Channel 10			Channel 11			Channel 12		
Byte No.	Byte37	Byte38	byte39	byte40	Byte41	Byte42	Byte43	Byte44	Byte45
Function	Channel 13			Channel 14			Channel 15		
Byte No.	Byte46	Byte47	Byte48						
Function	Channel 16								

Register description:

(1) The storage format of corrected vertical angle data adopts big endian format.

(2) LSB = 0.0001°

(3) The value of the vertical angle is unsigned integer. Channel 1 to Channel 8 pitches downwards, channel 9 to channel 16 pitches upwards.

For example, the calculation of vertical angle of channel 9:

byte1 = 0x00, byte2 = 0x27, byte3 = 0x10.

convert to decimal: byte1 = 0, byte2 = 39, byte3 = 16.

cor_pitch_9: $(0*256^2+ 39*256+16) *0.0001 = 1°$.

B.8 Serial Number(SN)

SN(6 bytes in total)						
Byte No.	1byte	2byte	3byte	4byte	5byte	6byte
Function	SN					

The Serial Number of each device adopts the same format as the MAC_Address, namely, a 6-byte hexadecimal number.

B.9 Software Version(SOFTWARE_VER)

SOFTWARE_VER(2 bytes in toatal)		
Byte No.	byte1	byte2
Function	SOFTWARE_VER	

It provides instruction for version compatibility of the upper-computer

B.10 UTC Time(UTC_TIME)

UTC Time (10 bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	year	month	day	hour	min	sec	ms	
Byte No.	byte9	byte10						
Function	μs							

Register description:

(1) Year

set_year								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_year[7:0]：data 0~255 corresponds year 2000 to year 2255.							

(2) Month

set_month								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	reserve	set_month[3:0]：1~12 month			

(3) Day

set_day								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	set_day[4:0]：1~31 day				

(4) Hour

set_hour								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	reserve	set_hour[4:0]：0~23 hour				

(5) Min

set_min								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	set_min[5:0]：0~59 min					

(6) Sec

set_sec								
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	reserve	reserve	set_sec[5:0]：0~59 sec					

(7) ms

set_ms								
Byte No.	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8
Function	reserve	reserve	reserve	reserve	reserve	reserve	ms[9:8]	
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_ms[7:0]							

Note：set_ms[9:0] value：0~999

(8) μs

set_μs								
Byte No.	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8
Function	reserve	reserve	reserve	reserve	reserve	reserve	us[9:8]	
Byte No.	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Function	set_μs[7:0]							

Note：set_μs[9:0] value：0~999

B.11 STATUS

Status (18bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	Idat1_reg			Idat2_reg			Vdat_12V_reg	
Byte No.	byte9	byte10	byte11	byte12	byte13	byte14	byte15	byte16
Function	Vdat_12V_M_reg		Vdat_5V_reg		Vdat_3V3_reg		Vdat_2V5_reg	
Byte No.	17byte	18byte						
Function	Vdat_1V2_reg							

Register description:

(1) Idat1 is sensor power supply current, Idat2 is top board power supply current. We use Idat to represent Idat1 or Idat2. Idat_reg contains 3 bytes to be Idat_reg[23:0]. Idat_reg[23] is symbol flag, while Idat_reg[22:0] is current value. The LSB for Idat is 1uA, the formula is as below:

$$Idat=\begin{cases} Idat\_reg[22:0]\cdots\cdots\cdots(Idat\_reg[23]=0) \\ -Idat\_reg[22:0]\cdots\cdots(Idat\_reg[23]=1) \end{cases}$$

For example, if byte1 = 0x8C, byte2 =0xD5 and byte3 = 0x00, then the current value is:

Idat = -Idat_reg[22:0] = -0x0CD500 uA = -840960uA≈-841 mA

(2) We have six different voltage, each voltage register has 2 bytes to be Vdat_reg[15:0]. Vdat_reg[15:12] is invalid, while Vdat[11:0] represent the voltage value. The six different voltage formula is as below:

$$Vdat\_12V = Vdat\_12V\_reg[11:0]/4096 * 2.5 * 12$$

$$Vdat\_12V\_M = Vdat\_12V\_M\_reg[11:0]/4096 * 2.5 * 12$$

$$Vdat\_5V = Vdat\_5V\_reg[11:0]/4096 * 2.5 * 4$$

$$Vdat\_3V3 = Vdat\_3V3\_reg[11:0]/4096 * 2.5 * 2$$

$$Vdat\_2V5 = Vdat\_2V5\_reg[11:0]/4096 * 2.5 * 2$$

$$Vdat\_1V2 = Vdat\_1V2\_reg[11:0]/4096 * 2.5 * 2$$

The unit above is volt (V).

B.12 Fault Diagnosis

Fault Diagnosis (40bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	reserve							
Byte No.	byte9	byte10	byte11	byte12	byte13	byte14	byte15	byte16
Function	reserve		cksum_st	manc_err1		manc_err2		gps_st
Byte No.	byte17	byte18	byte19	byte20	byte21	byte22	byte23	byte24
Function	temperature1_reg		temperature2_reg		temperature3_reg		temperature4_reg	
Byte No.	byte25	byte26	byte27	byte28	byte29	byte30	byte31	byte32
Function	temperature5_reg		Internal Debug					r_rpm1
Byte No.	byte33	byte34	byte35	byte36	byte37	byte38	byte39	byte40
Function	r_rpm2	reserve						

Register description:

(1) chksum_st represents the temperature compensation status. If chksum_st=0, the temperature compensation is working. If chksum_st=0, the temperature compensation is, the temperature compensation is abnormal.

(2) manc_err1 and manc_err2 are used to calculate the bit error rate of the data communication. manc_err1 represents 1bit error, while manc_err2 represents 2bit error. The error rate formula is as below:

$$manc\_err1\_per = manc\_err1/65536 * 100\%$$

$$manc\_err2\_per = manc\_err2/65536 * 100\%$$

When one of the manc_err1_per and manc_err1_per is zero, the system data communication is normal.

(3) Temperature1 and temperature2 represent the bottom board temperature, while temperature3 and

temperature4 represent the top board temperature. Each temperature register contains 2 bytes to be temperature_reg[15:0]. temperature_reg[2:0] is invalid. temperature_reg[15:3] is temperature value, while temperature_reg[15] is symbol flag. The temperature formula is as below:

$$temperature1\_4 = \begin{cases} temperature[15:3] \quad /16 & (temperature[15] = 0) \\ -((8192 - temperature[15:3])/16) & (temperature[15] = 1) \end{cases}$$

Temperature5 represents bottom board temperature. The temperature register contains 2 bytes to be temperature_reg[15:0]. temperature_reg[15:12] is invalid. temperature_reg[11:0] is temperature value, while temperature_reg[15] is symbol flag

$$temperature5 = \begin{cases} temperature[11:0]/4 & (temperature[11] = 0) \\ -(4096 - temperature[11:0])/4 & (temperature[11] = 1) \end{cases}$$

(4) Byte16 represents the GPS input status register gps_st, this register uses 3 bit to describe the validation for PPS, GPRMC, and time stamp. The details are shown below:

GPS input status register: gps_st			
BIT	Function	Value	Status
bit0	PPS Flag: PPS_LOCK	0	PPS is invalid
		1	PPS is valid
bit1	GPRMC Flag： GPRMC_LOCK	0	GPRMC is invalid
		1	GPRMC is valid
bit2	UTC Lock Flag: UTC_LOCK	0	LiDAR internal time stamp is not synchronizing the UTC.
		1	LiDAR internal time stamp is synchronizing the UTC.
bit3~bit7	Reserved	x	N/A

(5) The real-time rotation speed of the motor is composed of two bytes, byte32 and byte33. The calculation formula is as follows:

Motor real-time rotation speed = (256 * r_rpm1 r_rpm2)÷6

(6) The reset is used for debug, they are not opened.

B.13 ASCII code in GPRMC Packet

GPRMC register reserve 86byte, it can store the whole GPRMC message from GPS module in to the register in ASCII code.

Appendix C ▪ RSView

This appendix gets you started with RSView. It shows you how to use the application to acquire, visualize, save, and replay sensor data. You can examine sensor data with other free tools, such as Wireshark or tcp-dump. But to visualize the 3D data, use RSView. It's free and relatively easy to use. The version used this time is RSView3.1.5.

C.1 Features

RSView provides real-time visualization of 3D LiDAR data from RoboSense LiDAR sensors. RSView can also playback pre-recorded data stored in "pcap" (Packet Capture) files, but RSView still does not support pcapng files. RSView displays distance measurements from a RoboSense LiDAR sensor as point data. It supports custom-colored display of variables such as intensity-of-return, time, distance, azimuth, and laser ID. The data can be exported as XYZ data in CSV format. The previous versions of RSView do not support generating point cloud files in LAS, XYZ, or PLY formats, while the RSView 3.1.5 supports generating LAS format.

Functionality and features include:

- Visualize live streaming sensor data over Ethernet
- Record live sensor data in pcap files
- Visualize sensor data from a recording (pcap file)
- Interprets point data such as distance timestamp, azimuth, laser ID, etc.
- Tabular point data inspector
- Export to CSV format
- Ruler tool
- Display multiple frames of data simultaneously (Trailing Frames)
- Display or hide subsets of lasers
- Crop views

C.2 Install RSView

Installer for RSView is provided for Windows 64-bit system and it has no need for other dependencies. You can find the executable installer **RSView_X.X.X_Setup.exe** from the U disk in the RS-LiDAR-16 box. Also you can download the latest version from RoboSense website (http://www.robosense.ai/resource). Launch the installer and follow the on-screen instructions to finish the installation.

C.3 Set up Network

As mentioned in the RS-LiDAR-16 User's Manual, the default IP address of the computer should be set as 192.168.1.102, sub-net mask should be 255.255.255.0. You should make sure that RSView not be shielded by firewall in the computer.

C.4 Visualize Streaming Sensor Data

1. Connect the sensor to your computer and power it up.
2. Right Click to start the RSView application with Run as administrator.
3. Click on **File** > **Open** and select **Sensor Stream** (Figure C-1).

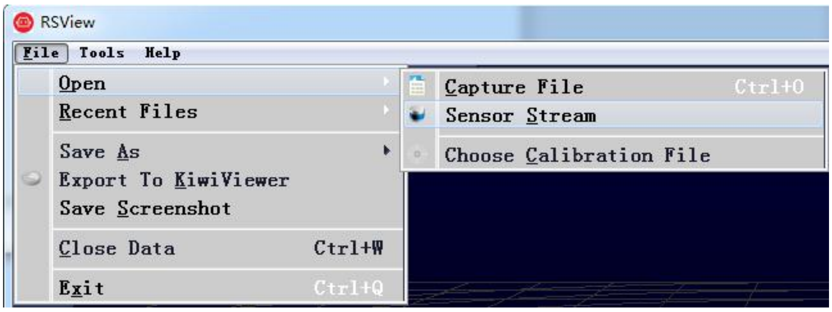


Figure C - 1: RSView Open Sensor Stream.

4. The Sensor Configuration dialog will appear. In "Type of Lidar", Chose RSlidar16. In "Intensity", chose Mode3. Then click "OK", shown as following Figure C-2:

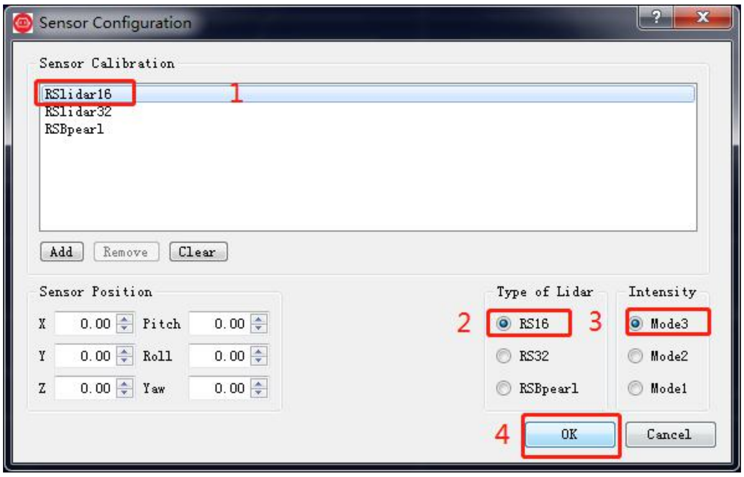


Figure C - 2: RSView Select Sensor Correction File.

5. RSView begins displaying the sensor data stream (Figure C-3). The stream can be paused by pressing the **Play** button. Press it again to resume streaming.

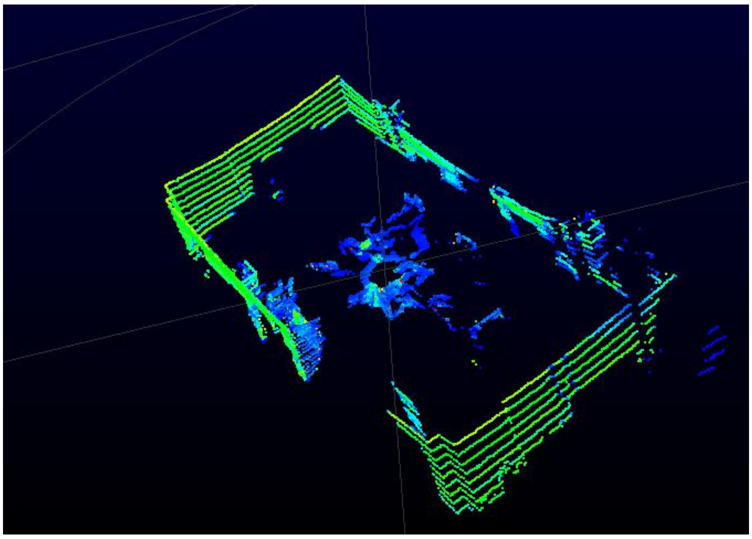


Figure C - 3: Sensor Stream Data Display in RSView .

C.5 Capture Streaming Sensor Data to PCAP File

1. Click the **Record** button when streaming (Figure C-4).

Figure C - 4: RSView Record Button.

2. A Choose Output File dialog will pop up. Navigate to where you want the file to be saved and click the **Save** button (Figure C-5). RSView begins writing packets to your pcap file. (***Note***: *RS-LiDAR-16 sensors generate a lot of data. The pcap file can become quite large if the recording duration is lengthy. Also, it is best to record to a fast, local HDD or SSD, not to a slow subsystem such as a USB storage device or network drive.*)

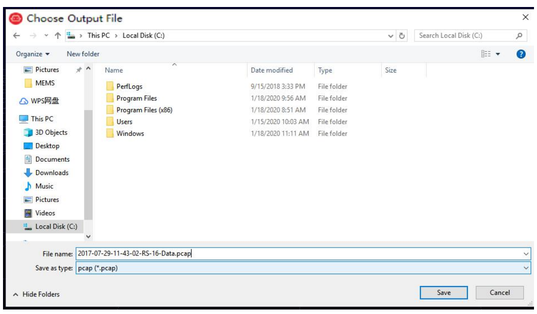


Figure C - 5: RSView Record Saving Dialog.

3. Recording will continue until the **Record** button is clicked again, which stops the recording and closes the pcap file.

C.6 Replay Captured Sensor Data from PCAP File

To replay (or examine) a pcap file, open it with RSView. You can press **Play** to let it run, or scrub through the data frames with the Scrub slider. Select a set of 3D rendered data points with your mouse and examine the numbers with a Spreadsheet sidebar.

1. Click on **File** > **Open** and select **Capture File** (Figure C-6).

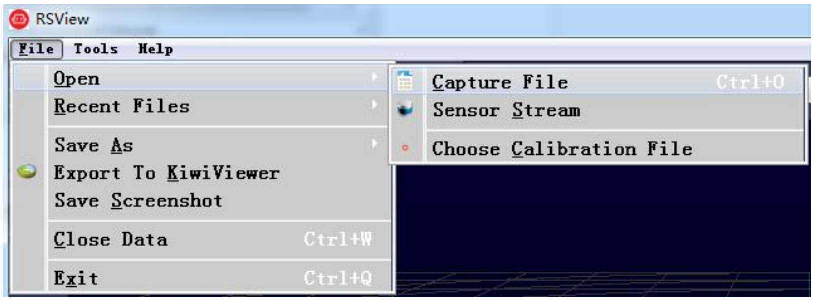


Figure C - 6: RSView Open Capture File.

2. An Open File dialog will pop up. Navigate to a pcap file, select it, and click the **Open** button.

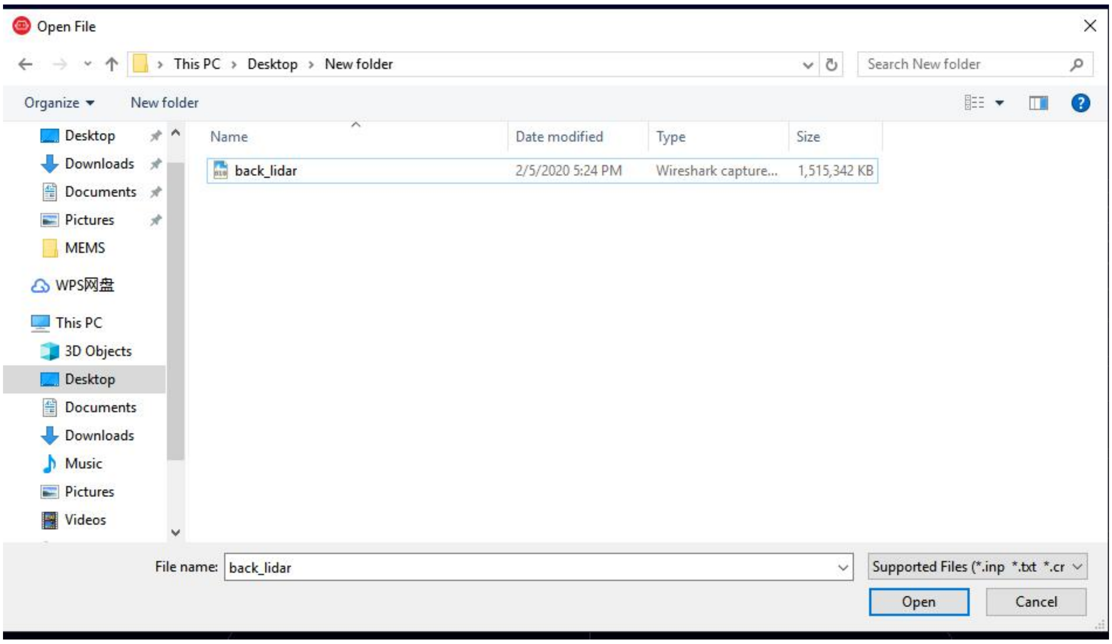


Figure C - 7: Select the PCAP File.

3. The Sensor Configuration dialog will pop-up. Select your sensor configuration folder and click **OK**.

4. Press **Play** to replay/pause the data stream. Use the **Scrub** slider tool (it looks like an old-fashioned volume slider) to move back and forth through the data frames. Both controls are in the same toolbar as the **Record** button (Figure C-8).

Figure C - 8: RSView Play Button.

5. To take a closer look at some data, scrub to an interesting frame and click the **Spreadsheet** button (Figure C-9). A sidebar of tabular data is displayed to the right of the rendered frame, containing all data points in the frame.

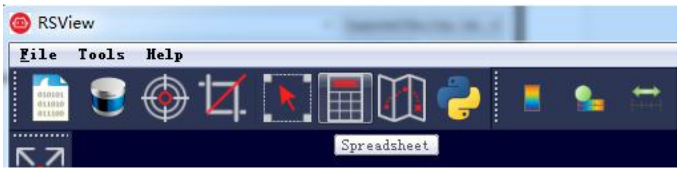


Figure C - 9: RSView Spreadsheet Tool.

6. Adjust the columns to get a better view of the numbers. If you've adjusted columns in Excel, some of this will be familiar. You can change column widths by dragging the column header divider left or right, and by double-clicking them. Drag column headers left or right to reorder them. Sort the table by clicking column headers. And you can make the table itself wider by dragging the table's sides left or right. Make Points_m_XYZ wider to expose the XYZ points themselves.

Showing: Data Attribute: Point Data Precision: 3

	Point ID	Points	adjustedtime	azimuth	distance_m	intensity	laser_id	timestamp
0	739	1.776…	998301570.000	993	10.380	5	11	998301570
1	752	1.814…	998301620.000	1011	10.415	6	11	998301620
2	753	1.820…	998301623.000	1012	10.390	25	12	998301623
3	754	1.829…	998301626.000	1013	10.390	13	13	998301626
4	766	1.846…	998301670.000	1029	10.415	6	11	998301670
5	767	1.861…	998301673.000	1030	10.440	25	12	998301673
6	768	1.861…	998301676.000	1031	10.390	13	13	998301676
7	769	1.871…	998301679.000	1032	10.410	33	14	998301679
8	780	1.877…	998301720.000	1047	10.410	6	11	998301720
9	781	1.893…	998301723.000	1048	10.440	25	12	998301723
10	782	1.896…	998301726.000	1049	10.405	13	13	998301726
11	783	1.906…	998301729.000	1050	10.425	40	14	998301729

Figure C - 10: RSView Data Point Table.

7. Click **Show only selected elements** in the Spreadsheet (Figure C-11). Since no points are selected yet, the table will be empty.

Showing: Data Attribute: Point Data Precision: 3

	Point ID	Points	adjustedtime	azimuth	distance_m	intensi Show only selected elements.	…stamp
0	739	1.776…	998301570.000	993	10.380	5	11	998301570
1	752	1.814…	998301620.000	1011	10.415	6	11	998301620

Figure C - 11: RSView Show Only Selected Elements.

8. Click the **Select All Points** tool. This turns your mouse into a point selection tool (Figure C-12).

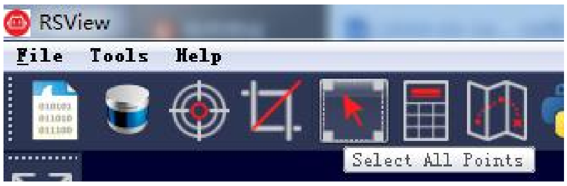


Figure C - 12: RSView Select All Points.

9. In the 3D rendered data pane use your mouse to draw a rectangle around a small number of points. They will immediately populate the data table (Figure C-13).

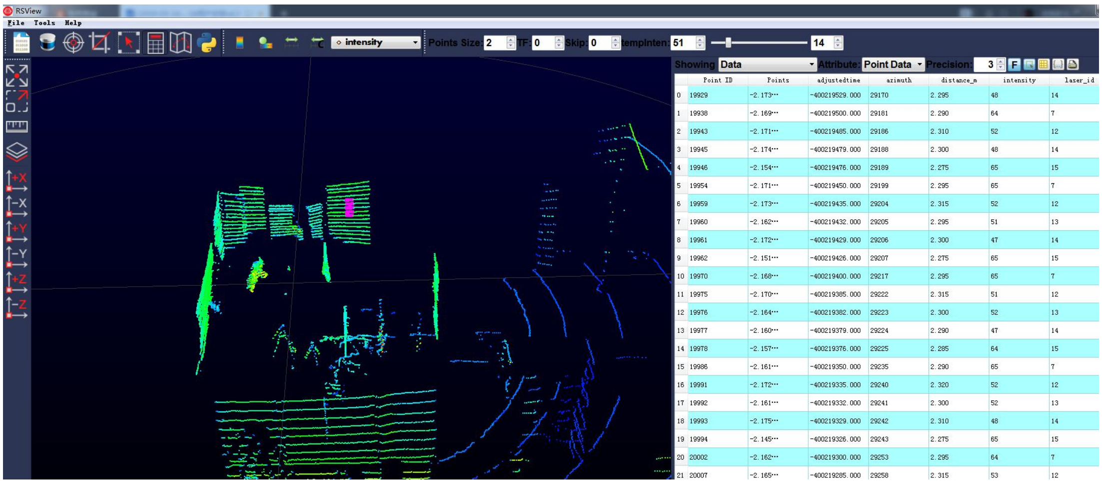


Figure C - 13: RSView List Selected Points.

10. At any selected point you can save a subset of data frames by doing Spreadsheet>Show only selected elements>Output CSV data.

C.7 RS-LiDAR-16 Factory Firmware Parameters Setting

RSView provide a tool which integrates UCWP function. We can use this tool to modify Rotation Speed, Network, Time, Optional output angle and Return mode in the RS-LiDAR-16 factory firmware.

1. We need connect RS-LiDAR-16 to the PC and confirm we can view the real time data. Then click **Tools > RS-LiDAR Information**.

2. A RS-LiDAR Information dialog will appear. Click **Get** button, it will display the current RS-LiDAR-16 parameters setting.

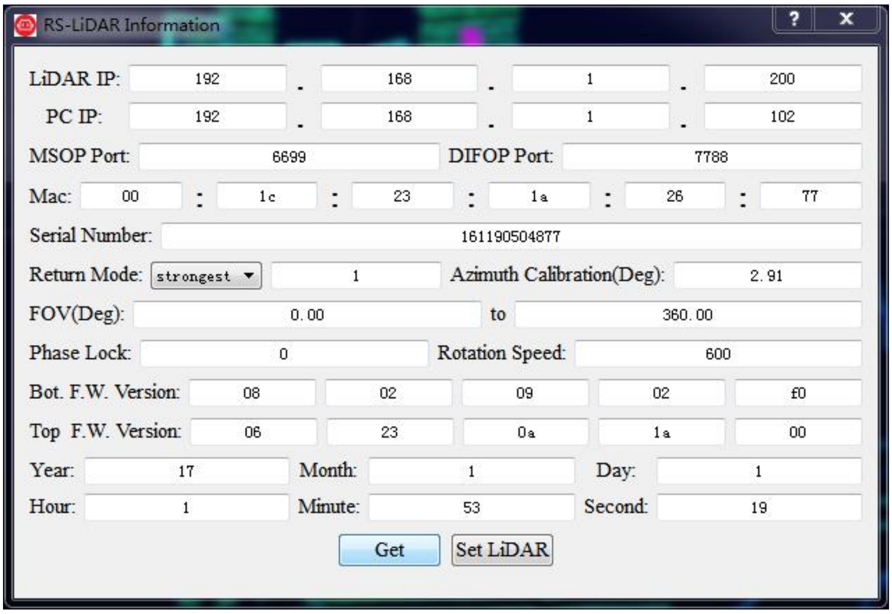


Figure C - 14: RS-LiDAR Information.

3. We can modify the parameters to the ones we want to have, then click **Set LiDAR**. We need re-power and connect the RS-LiDAR-16 to make the modified parameters valid. After the device connecting again, we can use RSView to see the RS-LiDAR Information again to check if the modification take effect.

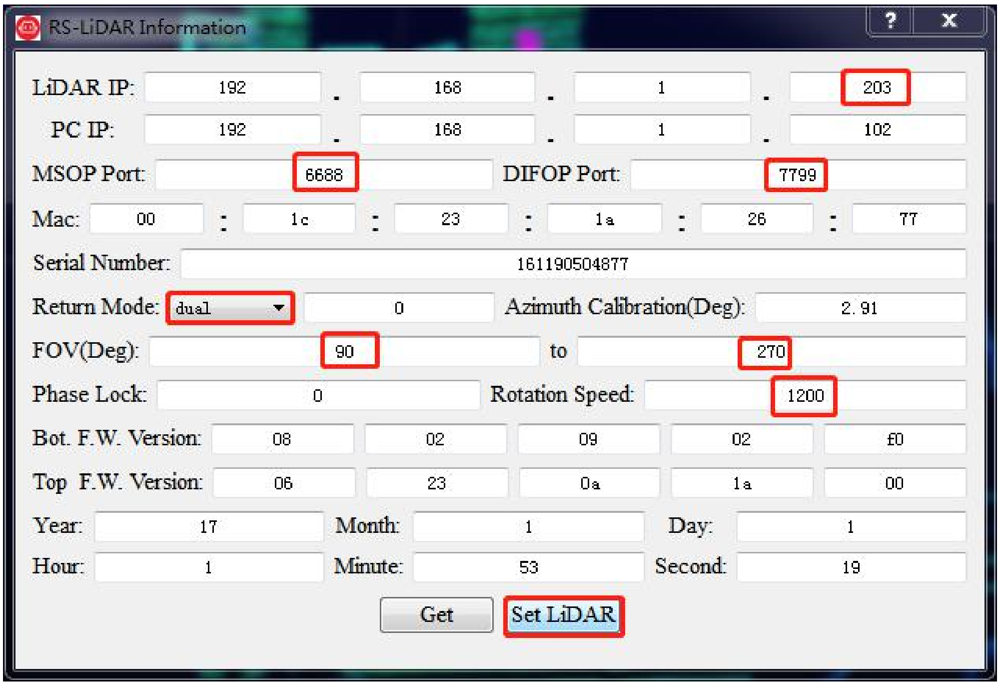


Figure C - 15: Set LiDAR information.

Attention 1： Please do not power off the sensor when we are setting LiDAR information, it may cause the sensor internal parameters broken.

Attention 2: if we modify the MSOP Port or DIFOP parameters above, we need setting the RSView MSOP Port and DIFOP Port according to C.8 section to make RS-LiDAR-16 can be connected correctly.

C.8 RSView Data Port

In the RS-LiDAR-16 factory firmware, the default MSOP port is 6699, the default DIFOP port is 7788, if we change the RS-LiDAR-16 ports number by modify the 2 parameters in C.7 section, we need configure the RSView Data Port first or we will see nothing in the RSView. If we do not know the RS-LiDAR-16 ports configuration, we can use Wireshark to capture the packets to check the Dst Port.

Click **Tools > Data Port**, enter the real MSOP port and DIFOP port of RS-LiDAR-16, then click **Set Data Port**. After that we can see the cloud point data again in the RSView.

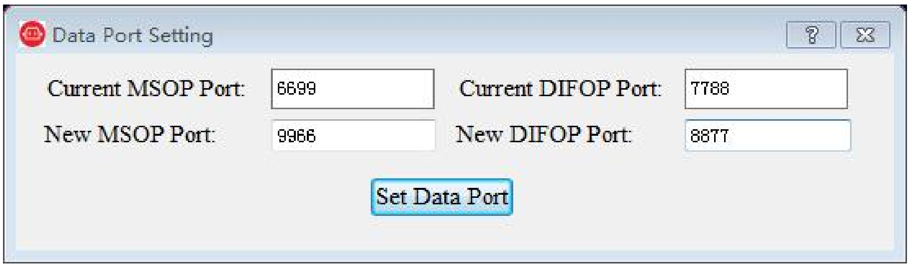


Figure C - 16: Data Port Setting.

C.9 Firmware Online Update

Before begin firmware online update, we need make sure the RS-LiDAR-16 is working normally, that means we can view the Pointcloud and get LiDAR information in RSVIEW.

Click **Tools > Online Update**, we can select the top board firmware update and bottom board firmware update as shown in Figure C-17.

Figure C - 17: Online Update.

For example, when we choose “Bottom Board Update”, we need direct to choose the “.rpd” firmware file for update, and then click Open to begin the online update process. The online update process would take some time, if the firmware update successfully, it will show “Online Update Successful”.

Note: *The Config Update option is not available.*

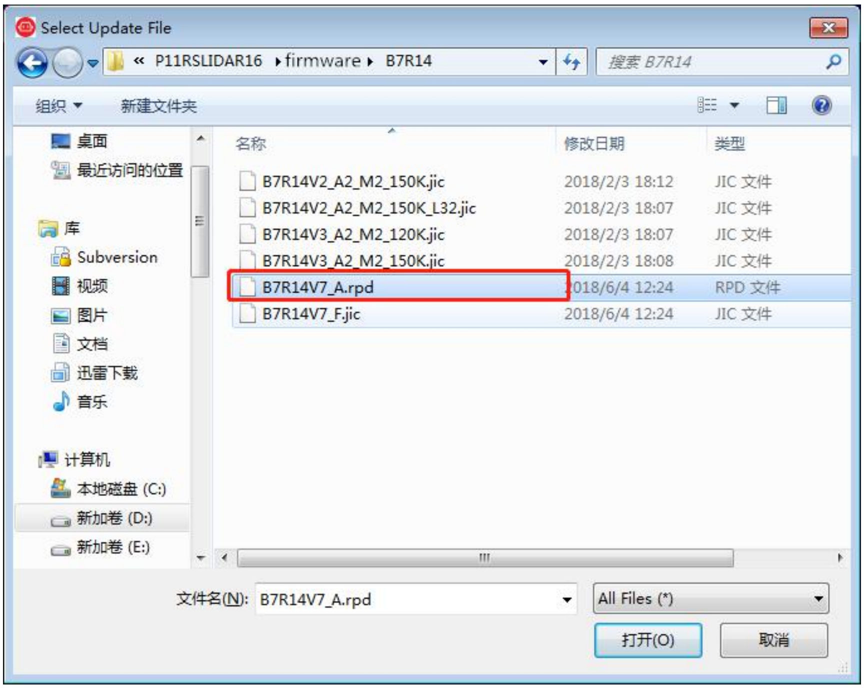


Figure C - 18: Select the Firmware for Update.

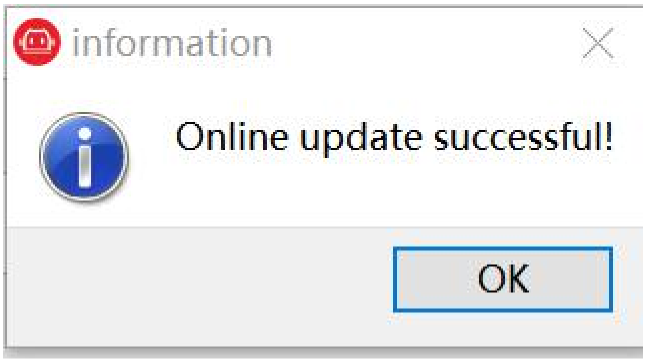


Figure C - 19: Online Update successful.

C.10 Fault Diagnosis

Before begin firmware online update, we need make sure the RS-LiDAR-16 is working normally, that means we can view the point cloud and get LiDAR information in RSVIEW.

Click **Tools > Fault Diagnosis**，the Fault Diagnosis window will pop up. Then we can click Start button to monitor the LiDAR status in real time, including current, voltage, temperature, error rate of the data communication, etc.

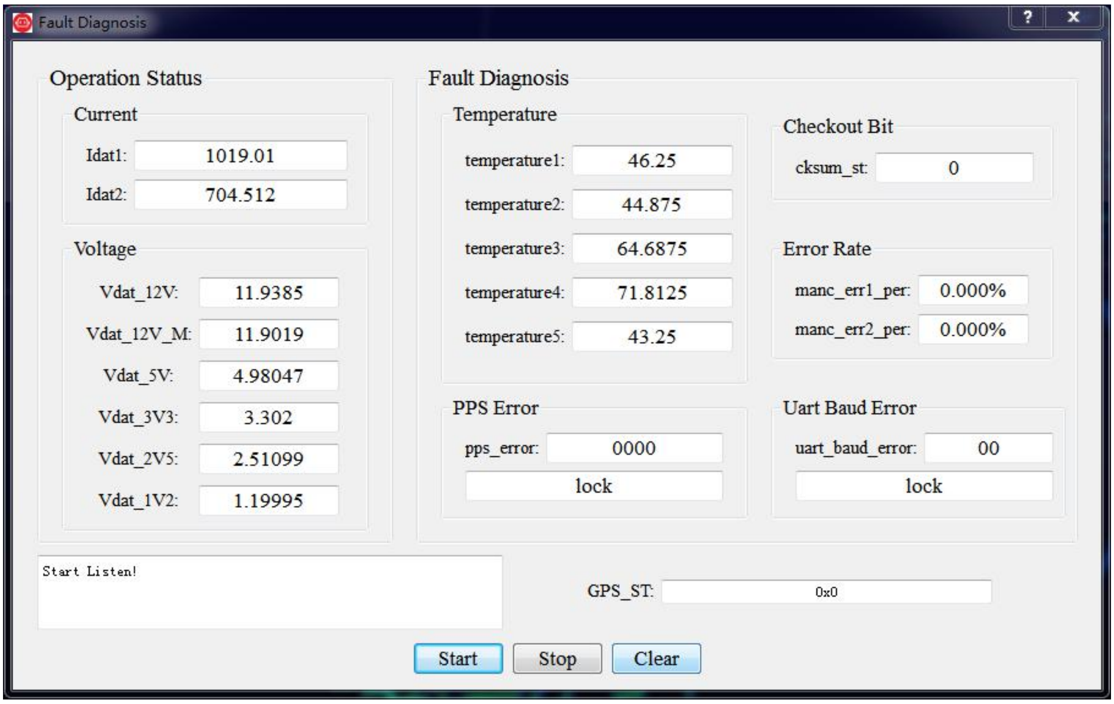


Figure C - 20: Fault Diagnosis.

Appendix D ▪ RS-LiDAR-16 ROS Package

This appendix describes how to use ROS to view the RS-LiDAZR-16 data.

D.1 Prerequisite

1. Download and install Ubuntu 16.04.
2. Please refer the link (http://wiki.ros.org/kinetic/Installation) to install the ROS kinetic version.
3. Download and install libpcap-dev.

D.2 Install RS-LiDAR-16 ROS Package

1. Create the work space for ros:

```
cd ~
mkdir -p catkin_ws/src
```

2. Copy the ros_rslidar_package into the work space ~/catkin_ws/src. You can find the ros_rslidar package in the U disk in the RS-LiDAR-16 box. You can also ask RoboSense to get these files. The latest version of the ros_rslidar driver can be downloaded from

https://github.com/RoboSense-LiDAR/ros_rslidar.

3. Build

```
cd ~/catkin_ws
catkin_make
```

4. Place the configuration file corresponding to the LiDAR：

The configuration file is in the USB disk shipped with the LiDAR. You need to copy the .csv file in the configuration_data folder from the USB disk to the folder specified in the launch file. This path can be customized. For example: rslidar_pointcloud/data/rs_lidar_16.

Note: If there are not configuration files in USB stick or a USB stick, use the configuration by default.

D.3 Configure PC IP address

For the default RS-LiDAR-16 firmware, it is configured the “192.168.1.200” as its own IP address, and the “192.168.1.102” as its destination PC IP address. So we need set the PC static IP as “192.168.1.102” and the net mask as “255.255.255.0”, while the gateway address is not necessary.

After configuration, we can use “ifconfig” command to check if the IP is work.

D.4 View the real time data

1. Connect the RS-LiDAR-16 to your PC via RJ45 cable, and power on it.

2. We have provided an example launch file under rslidar_pointcloud/launch to start the node, we can run the launch file to view the real time point cloud data. Open a terminal:

```
cd ~/catkin_ws

source devel/setup.bash

roslaunch rslidar_pointcloud rs_lidar_16.launch
```

3. Open a new terminal:

```
rviz
```

Set the Fixed Frame to "rslidar". Add a Pointcloud2 type and set the topic to "rslidar_points":

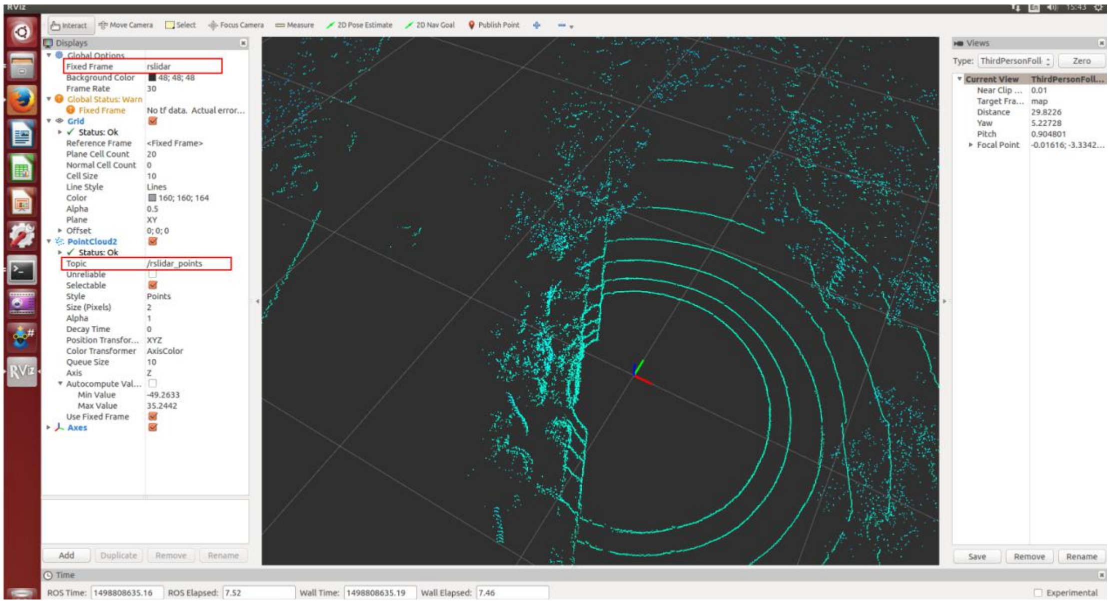


Figure D - 1: Rviz displays point cloud data of RS-LiDAR-16.

D.5 View the recorded pcap file offline

We can also use the ros_rslidar ROS package to view the recorded .pcap data.

1. Modify the "**rs_lidar_16.launch**" file to something like below (please pay attention to the red line):

```
<launch>

  <arg name="model" default="RS16" />

  <arg name="device_ip" default="192.168.1.200" />

  <arg name="msop_port" default="6699" />

  <arg name="difop_port" default="7788" />

  <arg name="lidar_param_path" default="$(find rslidar_pointcloud)/data/rs_lidar_16/"/>

  <node   name="rslidar_node" pkg="rslidar_driver" type="rslidar_node" output="screen" >
```

```
    <param name="model" value="$(arg model)"/>
    <param name="device_ip" value="$(arg device_ip)" />
    <param name="msop_port" value="$(arg msop_port)" />
    <param name="difop_port" value="$(arg difop_port)"/>
    <param name="pcap"   value="the absolute path to your .pcap file"/>
  </node>
  <node   name="cloud_node" pkg="rslidar_pointcloud" type="cloud_node" output="screen" >
    <param name="model" value="$(arg model)"/>
    <param name="curves_path" value="$(arg lidar_param_path)/curves.csv" />
    <param name="angle_path" value="$(arg lidar_param_path)/angle.csv" />
    <param name="channel_path" value="$(arg lidar_param_path)/ChannelNum.csv" />
  </node>
  <node name="rviz" pkg="rviz" type="rviz"   args="-d $(find rslidar_pointcloud)/rviz_cfg/rslidar.rviz" />
</launch>
```

2. Open a terminal, run node program:

```
cd ~/atkin_ws
source devel/setup.bash
roslaunch rslidar_pointcloud rs_lidar_16.launch
```

3. Open a new terminal and run：

```
rviz
```

Appendix E ▪ Dimensions

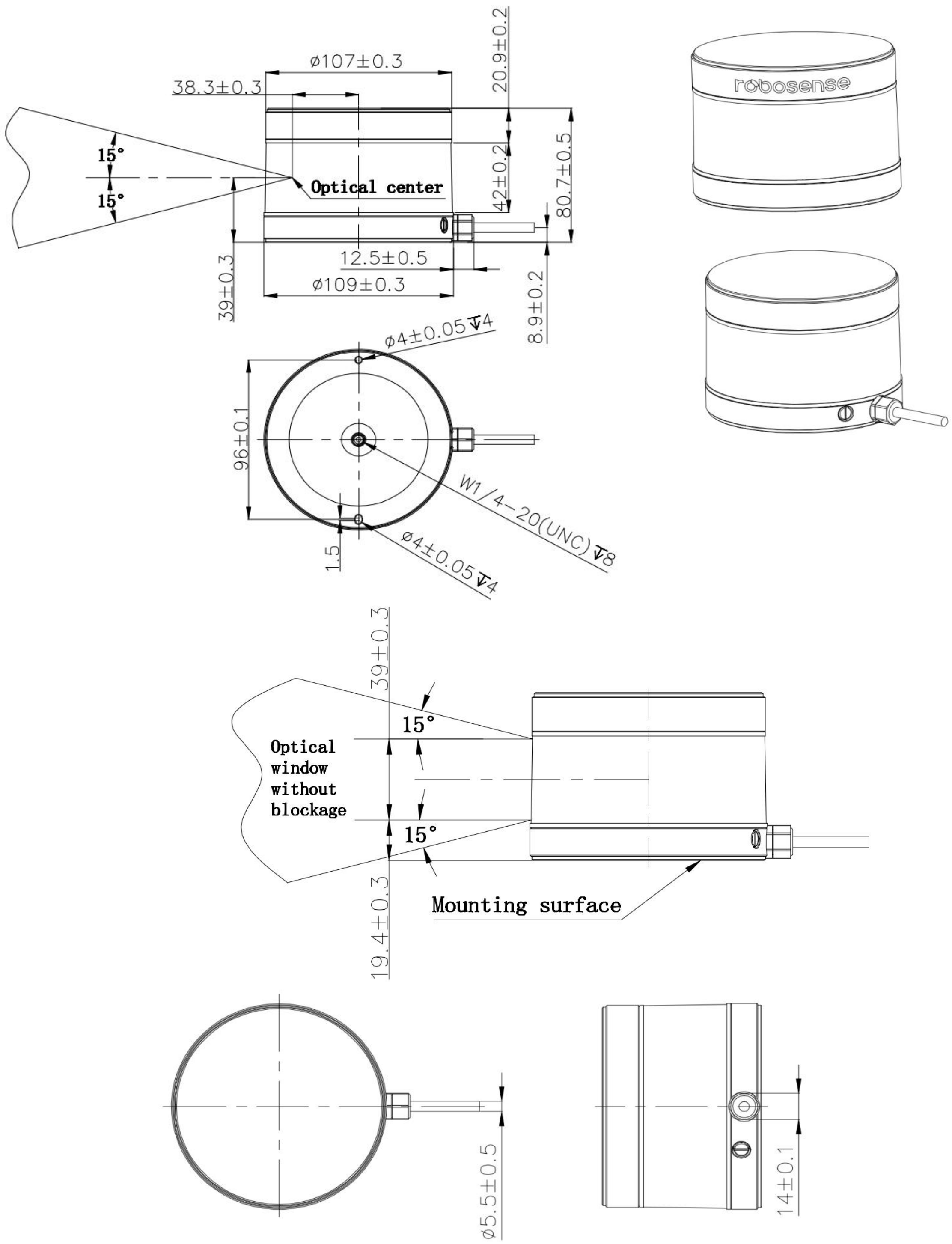


Figure E - 1: Dimension Image of LiDAR.

Appendix F ▪ LiDAR Mechanical Installation Suggestion

Please make sure the platform surface used for mount LiDAR is smooth as possible.

Please make sure the locating pin on the mount surface do exceed 4mm high.

The material of the mount platform is suggested to be aluminum alloy in order to thermolysis.

When the LiDAR is installed, if there is a contact mounting surface on the upper and bottom sides of the LiDAR, make sure that the spacing between the mounting surfaces is greater than the height of the LiDAR to avoid squeezing the LiDAR.

We do not suggest to mount the LiDAR in a tilt position that the tilt angle exceed 90 degrees, this will reduce the sensor life time.

When we route the LiDAR cable in the mount device, we need keep the cable a little slack.

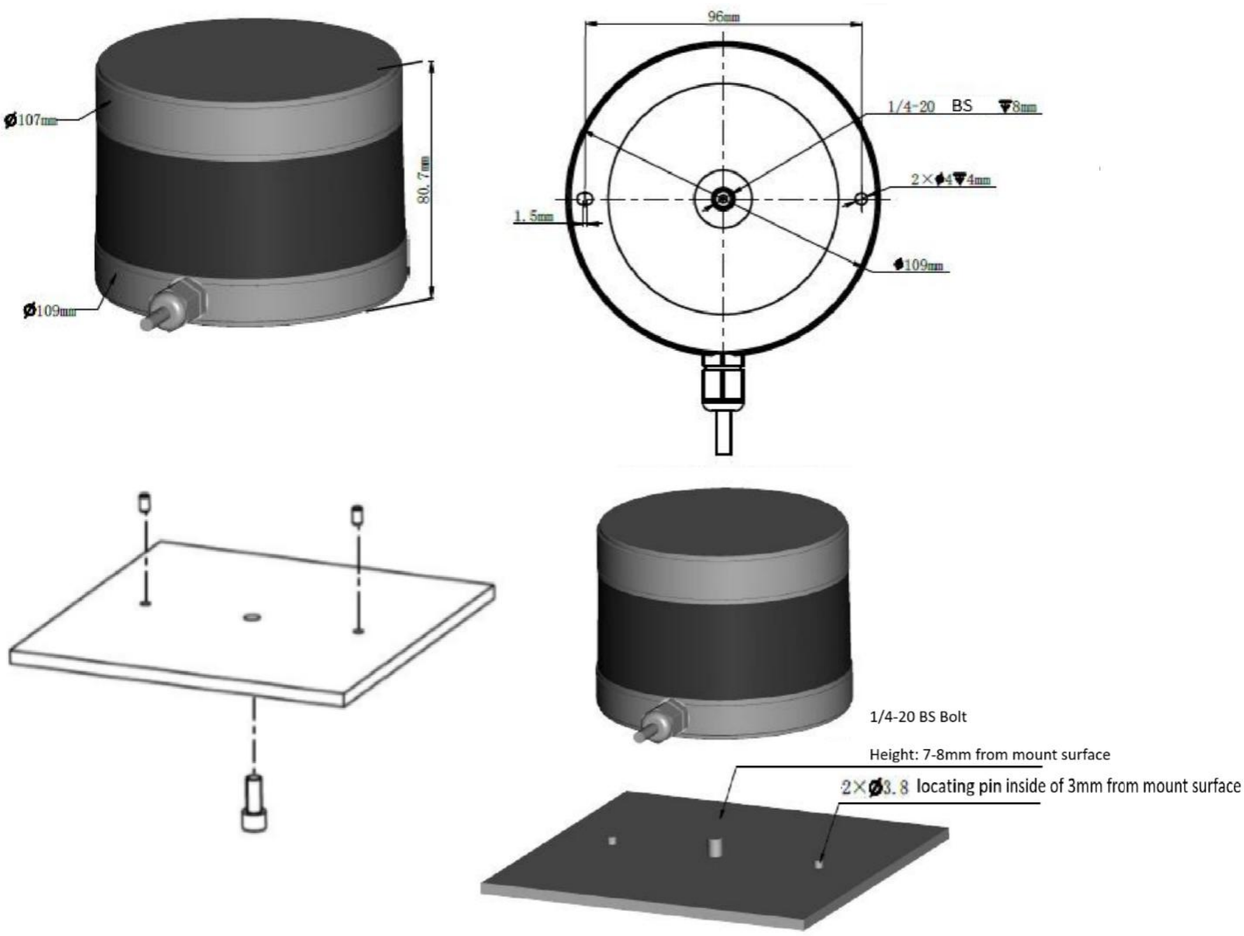


Figure F - 1: LiDAR Mounting Image.

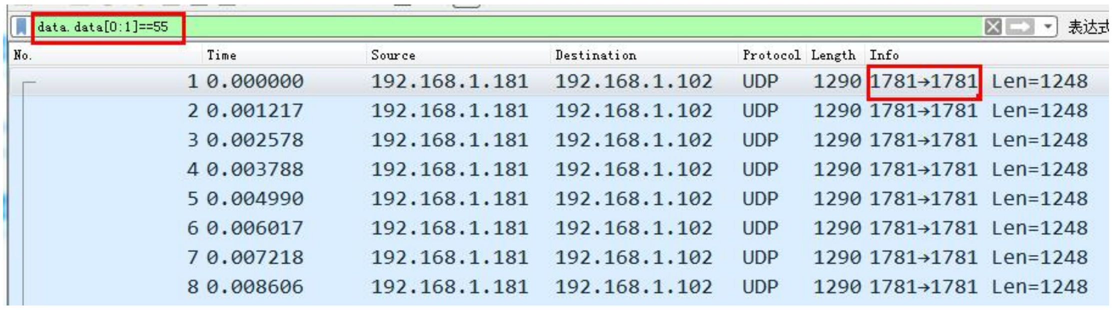
Appendix G ▪ How to Distinguish the Port Number of MSOP and DIFOP Packets

According to the Chapter 5, RS-LiDAR-16 outputs MSOP packets and DIFOP packets. We can use the Wireshark software to filter the MSOP packets or DIFOP packets so that we can know which port number the packets send to. After that we can set the Data Port in the RSVIEW.

We first need connect the RS-LiDAR-16 to the PC and power on the RS-LiDAR-16. The we can start the Wireshark and select the right network to begin capturing the packets.

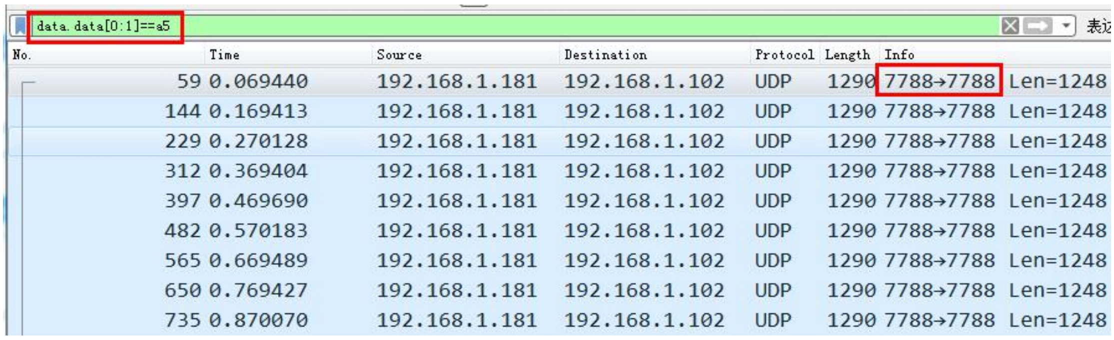
In the Display Filter, we can enter **data.data[0:1]==55** expression to filter the MSOP packets, then we can see the port number in the Info column, as shown in Figure G-1.

In the Display Filter, we can enter **data.data[0:1]==a5** expression to filter the DIFOP packets, then we can see the port number in the Info column, as shown in Figure G-2.



No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
2	0.001217	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
3	0.002578	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
4	0.003788	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
5	0.004990	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
6	0.006017	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
7	0.007218	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248
8	0.008606	192.168.1.181	192.168.1.102	UDP	1290	1781→1781 Len=1248

Figure G - 1: Wireshark filter the MSOP Packets.



No.	Time	Source	Destination	Protocol	Length	Info
59	0.069440	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
144	0.169413	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
229	0.270128	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
312	0.369404	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
397	0.469690	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
482	0.570183	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
565	0.669489	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
650	0.769427	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248
735	0.870070	192.168.1.181	192.168.1.102	UDP	1290	7788→7788 Len=1248

Figure G - 2: Wireshark filter the DIFOP Packets.

Appendix H ▪ Sensor clean

H.1 Attention

Please read through this entire Appendix H content before clean the RS-LiDAR. Improper handling can permanently damage it.

When the sensor is used in a harsh environment, it is necessary to clean the it in time to keep its performance.

H.2 Require Materials

1. Clean microfiber cloths

2. Mild, liquid dish-washing soap

3. Spray bottle with warm, clean water

4. Spray bottle with warm, mildly soapy water

5. Isopropyl alcohol

H.3 Clean Method

If the sensor is just covered by dust, use a clean microfiber cloth with a little isopropyl alcohol to clean the sensor directly, then dry with another clean microfiber cloth.

If the sensor is caked with mud or bugs, use a spray bottle with clean, warm water to loosen any debris from it. Do not wipe dirt directly off the sensor. Doing so may abrade the surface. Then use warm, mildly-soapy water and gently wipe the sensor with a clean microfiber cloth. Wipe the ring lens gently along the curve of the sensor, not top-to-bottom. To finish, spray the sensor with clean water to rinse off any remaining soap (if necessary, use isopropyl alcohol and a clean microfiber cloth to clean any remaining dirt from the sensor), then dry with another clean microfiber cloth.

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