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robosense
RS-Bpearl
User Manual
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Revision History

Revision Number	Description	Date	Edited by
1.0	Initial release	2019-08-14	PD
2.0	Update Figure Update dimension Update power consumption Update RSView Guide in Appendix C Update Appendix A Update footnote of Product Specification Update table of correspondence between laser channel and vertical angle	2019-12-11	PD
2.0.1	Update dimension drawing in Appendix E Modify some not precise description	2020-02-18	PD

Terminology

MSOP	Main data Stream Output Protocol
DIFOP	Device Info Output Protocol
UCWP	User Configuration Write Protocol
Azimuth	Horizontal Angle of LiDAR
Timestamp	Time Point of Encapsulation of a UDP Packet
Header	The Header of a UDP packet
Tail	The Tail of a UDP packet

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

1. Safety Notice

In order to reduce the risk of electric shock and to avoid violating the warranty, do not open sensor housing.

- **Laser safety** - The laser safety complies with IEC60825-1:2014.
- **Read Instructions** - All safety and operating instructions should be read before operating the product.
- **Follow the 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.
- **Maintenance** - The user should not attempt to maintain the product beyond what is described in the operating instructions. All other Maintenance should be referred to RoboSense.

2. Introduction

RS-Bpearl, the close-range LiDAR developed by RoboSense, is the world leading LiDAR for monitoring blind spot. It is particular utilized in and perception of environment for autonomous driving.

RS-Bpearl is realized by solid-state hybrid LiDAR. The technical details are listed below:

- Minimum measuring range: 10 cm
- Accuracy: within up to ± 2 centimeter
- Data rate up to 576,000 points/second
- Horizontal field of view (FOV) of 360°
- Vertical field of view (FOV) of 90°

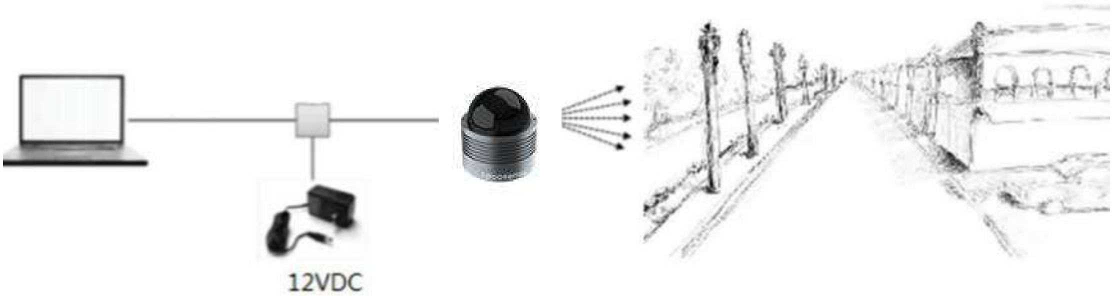


Figure 1:Representation of RS-Bpearl Imaging.

The operating Instructions of LiDAR:

- Connecting the device of RS-Bpearl;
- Parsing the data packets, in order to capturing the values of azimuth, measuring distance and calibrated reflectivity;
- Calculate X, Y, Z coordinates from reported azimuth, measured distance, and vertical angle;
- Storing the data of point cloud according to demand;
- Checking the status of set-up information of device;
- Resetting the status of network configuration, timing and rotation speed according to demand.

3. Product Specifications[1]

Table 1: Product Parameters.

Sensor	● TOF measuring distance, including the reflectivity ● Range: from 0.1 m to 30m (Reflectivity: 10%)[2] ● Accuracy: ±3cm (typical value)[3] ● FOV(vertical): 90° ● FOV (horizontal): 360° ● Angle resolution (horizontal/ azimuth): 0.2° (10 Hz)/0.4° (20 Hz) ● Rotation speed: 600/1200 rpm (corresponding to 10/20 Hz)
Laser	● Class 1 ● Wave length: 905nm ● Full angle of beam divergence: horizontal 9 mrad, vertical 17.8 mrad
Output	● Date rate: ~600k points/second ● 100M Ethernet ● Communication protocol: UDP ● The Information that is included in Dates Segment: Distance Rotation angle/Azimuth Calibrated reflectivity Synchronized timestamp (Timer resolution 1 us)
Mechanical/ Electrical/ Operational	● Power consumption: 13 W(typical)[4] ● Working voltage: 9-32 VDC ● Weight: 0.92 kg (without cable) ● Dimensions: Diameter 100 mm × Height 111 mm ● Ingress Protection Rating: IP67 ● Operation temperature: -30 ℃~+60 ℃[5] ● Storage temperature: -40 ℃~+85 ℃

[1] The following data is only for mass-produced products. Any sample, testing machine 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 range is a 10% 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.
[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.

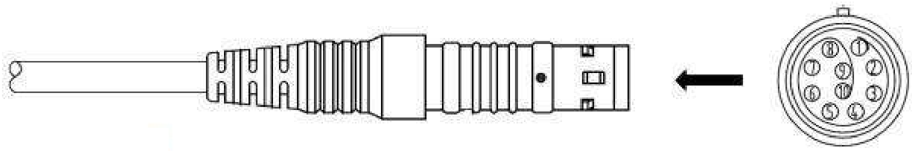
4. Interface

4.1 Power Supply

A voltage transform module is already integrated in RS-Bpearl. The supply voltage could keep in the range of 9~32 VDC with utilization of Interface-Box. The recommend supply voltage is 12 VDC. The operating power consumption is about 13 W (typical).

4.2 Data Output interface of LiDAR

The data output access of RS-Bpearl is physically protected by an aviation terminal connector. From the LiDAR to the aviation connector the cable length is 1 meter. The pins of the aviation terminal connector are defined as follow:

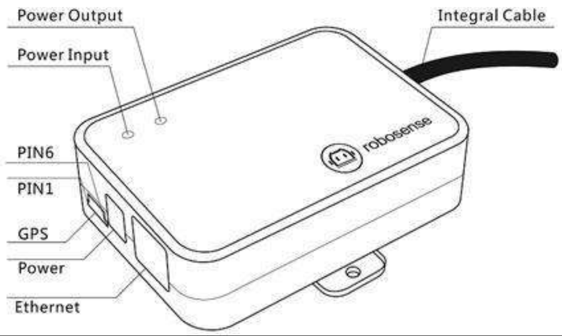


PIN	Wire Color	Function
1	Red	+12V
2	Yellow	+12V
3	White	GROUND
4	Black	GROUND
5	Green	GPS PULSE
6	Blue	GPS REC
7	Brown	LiDAR Ethernet RX+
8	Brown white	LiDAR Ethernet RX-
9	Orange	LiDAR Ethernet TX+
10	Orange white	LiDAR Ethernet TX-

Figure 2: Aviation Connector PIN Number.

4.3 Interface Box

In order to connect the RS-Bpearl conveniently, there is an interface box provided.
There are accesses for power supply, Ethernet and GPS on Interface Box. Meanwhile there are also indicator LEDs for checking the status of power supply.
For those accesses, an SH1.0-6P female connector is the interface for GPS signal input. Another interface is a DC 5.5~2.1 connector for power input. The last one is a Rj45 Ethernet connector for RS-Bpearl data transport. The length of the integral cable is 3 m, when the cable length needs to be shorten or extended, please contact RoboSense technical support, as shown in Figure 3.



PIN	Function
1	GPS PULSE
2	+5V
3	GND
4	GPS REC
5	GND
6	NC

Figure 3: Interface Definition Interface Box.

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

When the power input is in order, the red LED which indicates the power input status will be lighted. Meanwhile the green LED which indicates the power output status will be lighted, when the power output is in order. While red LED is bright and green LED is dark, Interface Box is in Protection status. While red and green LEDs are all dark, please check whether the power supply is out of order or damaged. If it is intact, that could prove that the Interface Box is damaged. Please send the damaged Interface Box back to RoboSense Service.

GPS interface definition: GPS REC stands for GPS input; GPS PULSE stands for GPS PPS input.

Interface of power supply is standard DC 5.5-2.1 connector.

4.4 Connection of Interface Box

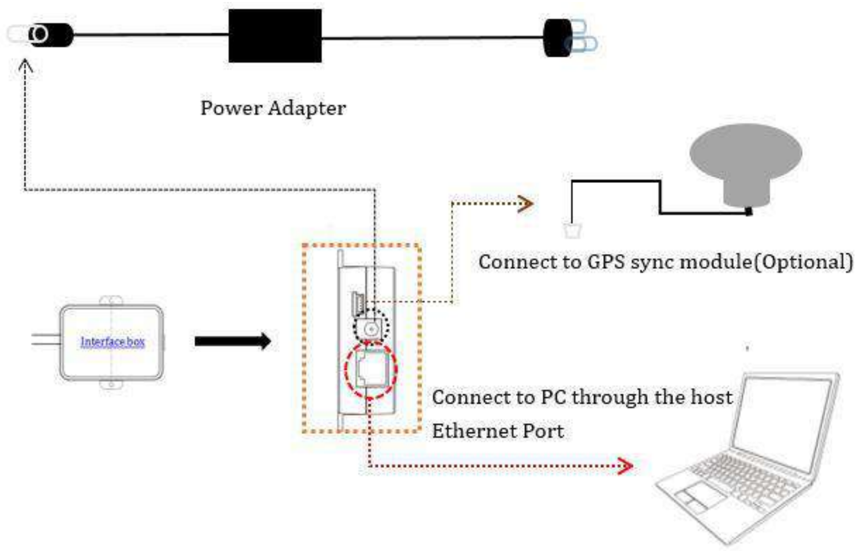


Figure 4: Diagram of Interface Box Connection.

5. Communication Protocol

RS-Bpearl adopts IP/UDP protocol and communicates with computer through Ethernet. In this User Guide, The UDP protocol packet in this manual is of 1290 byte long and consists of a 1248-byte valid payload and a 42-byte header. The IP address and port number of RS-Bpearl 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 in the Factory.

Device	IP Address	MSOP Port No.	DIFOP Port No.
RS-Bpearl	192.168.1.200	6699	7788
PC	192.168.1.102		

The default MAC Address of each RS-Bpearl is already set up in the factory with uniqueness. In order to establishing the communication between a RS-Bpearl and a computer, the IP Address of the computer should be set at the same network segment. For instance, IP Address is 192.168.1.X (X can be taken by a value from 1~254), subnet mask: 255.255.255.0. If the internet setting of the sensor is unknown, please set the subnet mask as 0.0.0.0, connect the sensor to the computer, and capture UDP packet to get the information of IP and Port through Wireshark.
RS-Bpearl adopts 3 kinds of communication 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: Overview of the MSOP.

Protocol	Abbreviation	Function	Type	Size	Interval
Main data Stream Output Protocol	MSOP	Scan Data Output	UDP	1248 bytes	~0.66 ms
Device Information Output Protocol	DIFOP	Device Information Output	UDP	1248 bytes	~100 ms
User Configuration Write Protocol	UCWP	Sensor Parameters Setting	UDP	1248 bytes	INF

Note: In the following chapters only the valid payload (1248 byte) will be discussed.

5.1 MSOP

MSOP is the abbreviation of Main Data Stream Output Protocol. 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 timestamp.
In each RS-Bpearl 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 5：

Figure 5: Single Return MSOP.

The basic data structure of a MSOP packet for dual return is as shown in Figure 6.

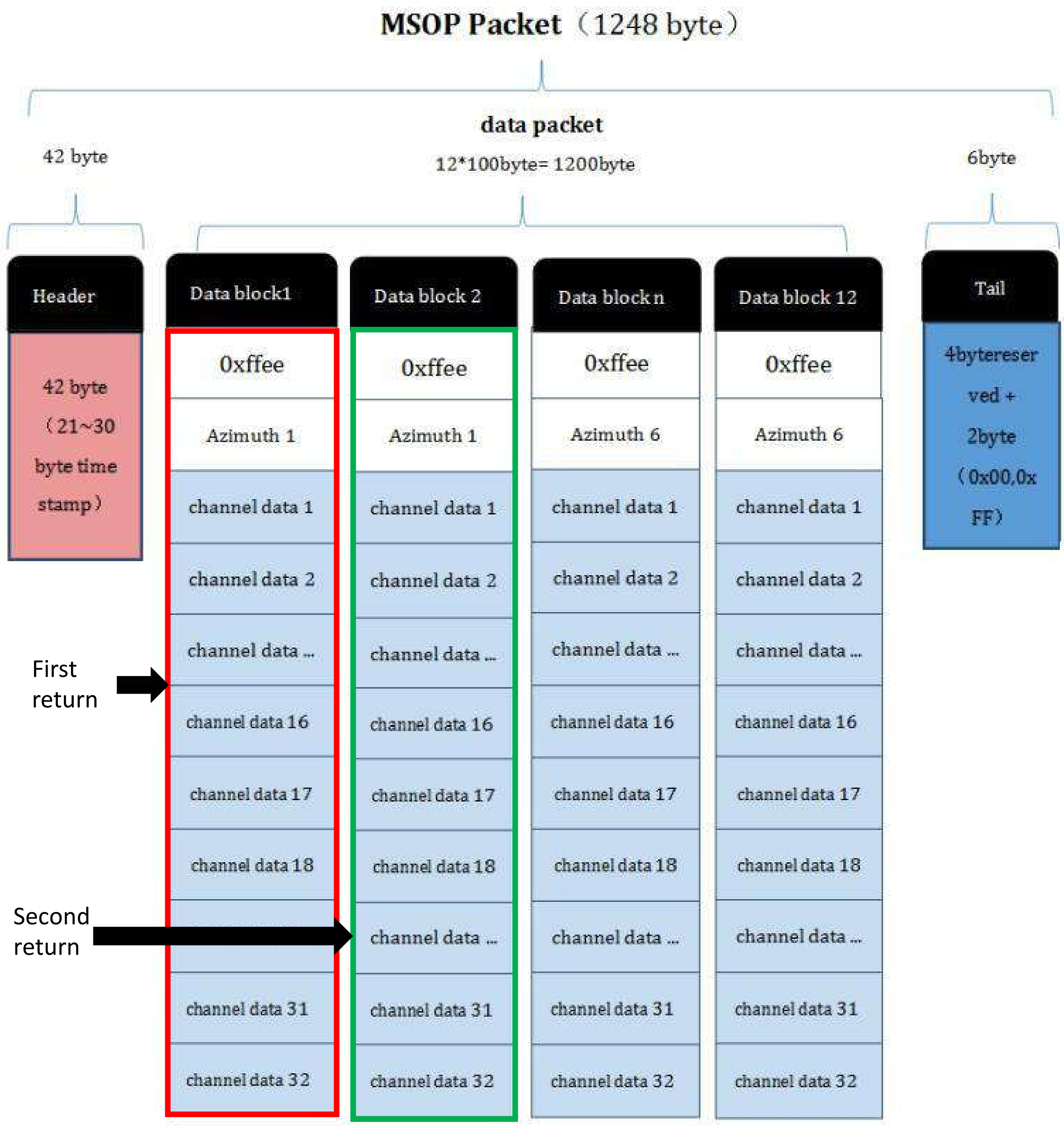


Figure 6: Dual Return MSOP.

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 timestamp, 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 1us records the system time. Please refer to the definition of time in Appendix B.9 and Table 6 in section 5.3 of this chapter.

5.1.2 Data Field

Data field comprises data blocks that contain valid measurement data, in total 1200 bytes. 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 32 laser channels. (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 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-Bpearl. The resolution of Azimuth is 0.01°.

For example, in Figure 8, the azimuth value is calculated through the following steps:

Get azimuth values: 0x61, 0x86
Combine to a 16 bit, unsigned integer: 0x6186 Convert to decimal: 24966
Divided by 100
Result: 249.66°

Hence, the firing angle is 249.66°

5.1.2.2 Channel Data

Channel Data contains 3 bytes, with the upper 2 bytes (16 bits in total) store distance information, and the lower 1 byte contains reflectivity data. The structure of channel data is as shown in Table 4.

Table 4： Channel Data Definition.

Channel data n (3 byte)		
2-byte Distance		1-byte Reflectivity
Distance1 [15:8]	Distance2 [7:0]	Reflectivity Information

The 2-byte distance data is set in centimeter. The distance resolution is 0.5 cm. The following shows how to parse channel data：

For example, in the case of Figure 8, the distance information is calculated by:

Get distance values: 0x01, 0xb4.
0x01 is the upper byte of distance, concert to decimal: 1.
0xb4 is the lower byte of distance, convert todecimal: 180.
*Hence, distance= upper byte of distance * 256 + lower byte of distance*

*= 1*256 + 180 = 436.*

According to distance resolution, *the distance: 435 * 0.05 = 2.18 m*.

Hence, *the measured distance is 2.18 m*.

5.1.3 Tail

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

5.1.4 MSOP Data Package

The following Figure 8 shows the format of MSOP data packet and relevant parsing processes.

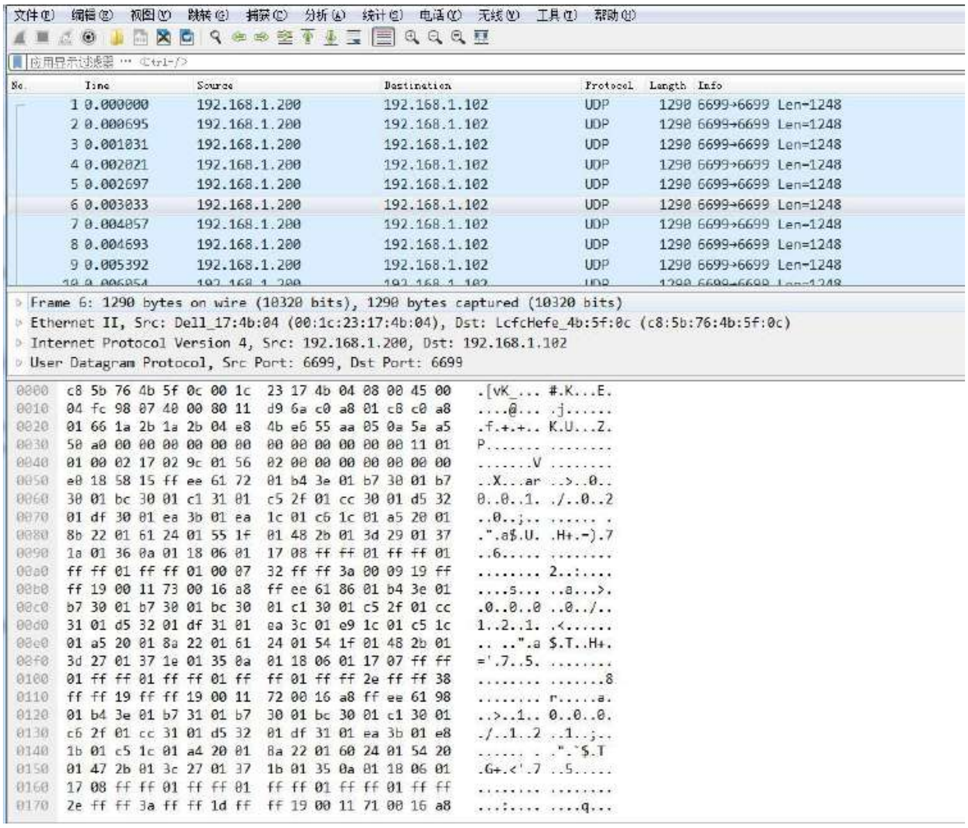


Figure 7: MSOP Packet.

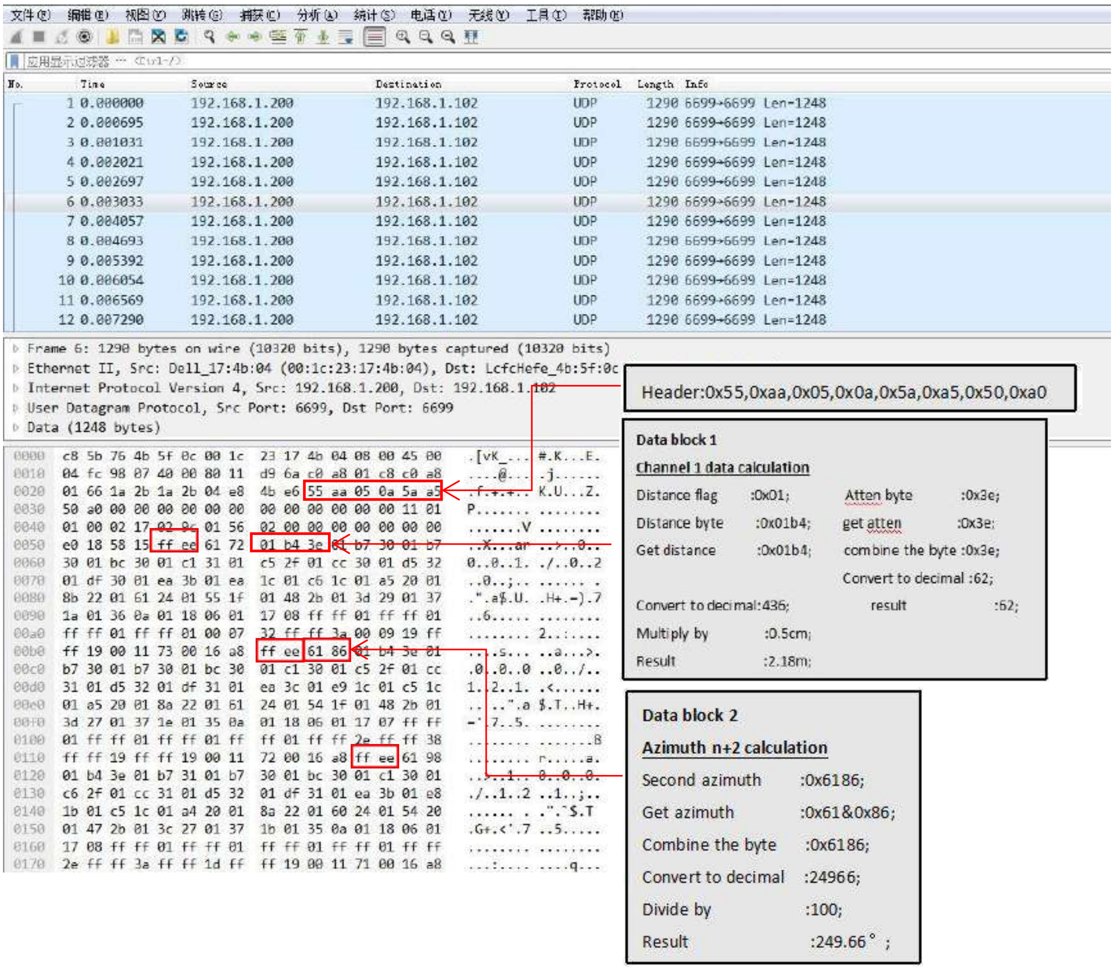


Figure 8: Details of MSOP Packet.

5.2 DIFOP

DIFOP is abbreviation of Device Info Output Protocol. 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 bytes 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 5.

Table 5: DIFOP Packet Definition.

Segment	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	Reserved	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	Reserved	50	242
	9	Serial number (SN)	292	6
	10	Zero angle offset	298	2
	11	Return mode	300	1
	12	Upper computer compatibility	301	2
	13	UTC time (UTC_TIME)	303	10
	14	Operation status (STATUS)	313	18
	15	Reserved	331	11
	16	Fault diagnosis (FALT_DIGS)	342	40
	17	GPRMC	382	86
	18	Corrected vertical angle	468	96
	19	Corrected horizontal angle	564	96
	20	Reserved	660	586
Tail	21	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 bytes long, and is comprised of a 8-byte Header and a 40-byte data field.
The UCWP packet structure is as shown in Table 6 below:

Table 6: UCWP Packet Definition.

Segment	No.	Information	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-Bpearl 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 Part 2, Section 10 of this manual for details on Ethernet, Time, Motor Rotation Speed and Motor Phase Lock.

Table 7: An Example for corresponding value of Setting.

Information	Content	Setting	Length/byte
Header		0xAA,0x00,0xFF, 0x11,0x22,0x22, 0xAA,0xAA	8
Rotate Speed	600rpm	0x02 0x58	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 start 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-Bpearl. 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-Bpearl supports external GPS receiver connections. With GPS connections, we can synchronize the RS-Bpearl 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 20 ms to 200 ms, and the GPRMC message should be received within 500 ms after the PPS signal is generated.

6.2 GPS Usage

There is only one level protocol for RS-Bpearl GPS_REC pins: RS232 level standard
The GPS interface on the Interface BOX is SH1.0-6P female connector, the pin definition is as shown in Figure 3.
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 as follows:
Pin +5V can supply the power for GPS module. (Please do not connect the GPS into the +5V pin if the GPS is 3.3V power supply. Also please do not input the power into the +5V pin because the pin is an output.)
Pin GND provide the ground connection for GPS module.
The GPS module should set to 9600bps baud rate, 8-bit data bit, no parity and 1 stop bit.
RS-Bpearl 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-Bpearl reserve 86byte space for GPRMC message, so it can be compatible with the majority GPS module in the market.

7. Key Characteristic

7.1 Return Mode

7.1.1 Return Mode Principle

RS-Bpearl supports multiple return modes: Strongest return, Last return, and Dual return modes. When set to dual return mode, the details of the target will be enhanced, and the number of point 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 high reflective surface may be the opposite.
RS-Bpearl 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 reflected 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.

7.1.1The Strongest Return

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

7.1.2Strongest, Last and Dual Returns

When the laser pulse hit 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.

7.1.3Return Mode Flag

The factory default setting for RS-Bpearl 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 8: Interchange between Return Mode and Flag Position.

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

7.2 Phase Lock

When using multiple RS-Bpearl 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-Bpearl 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.

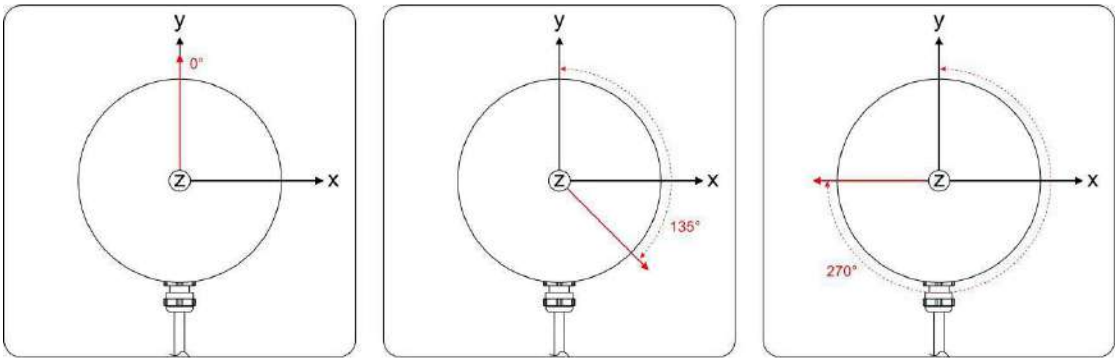


Figure 9: Different phase lock angles 0°/135°/270°.

The red arrows in Figure 9 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.
Only if the rotate speed is set to 600 rpm / 1200 rpm, the function of phase lock can be worked.

8. Point Cloud

8.1 Coordinating Mapping

In data packet including the measured azimuth and distance, in order to calculating the point cloud, the coordinate in polar coordinate system should be transferred to the 3D XYZ coordinate in Cartesian Coordinate System, as shown in figure 10. The function of how to transfer the information is as shown below:

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

Here r is the reported distance, ω is the vertical 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. δ is the angle offset of the azimuth. x, y, z values are the projection of the polar coordinates on the XYZ Cartesian Coordinate System.
The angle.csv file including ω and δ can be exported from RSView. Please refer to Appendix B.13 and B.14.

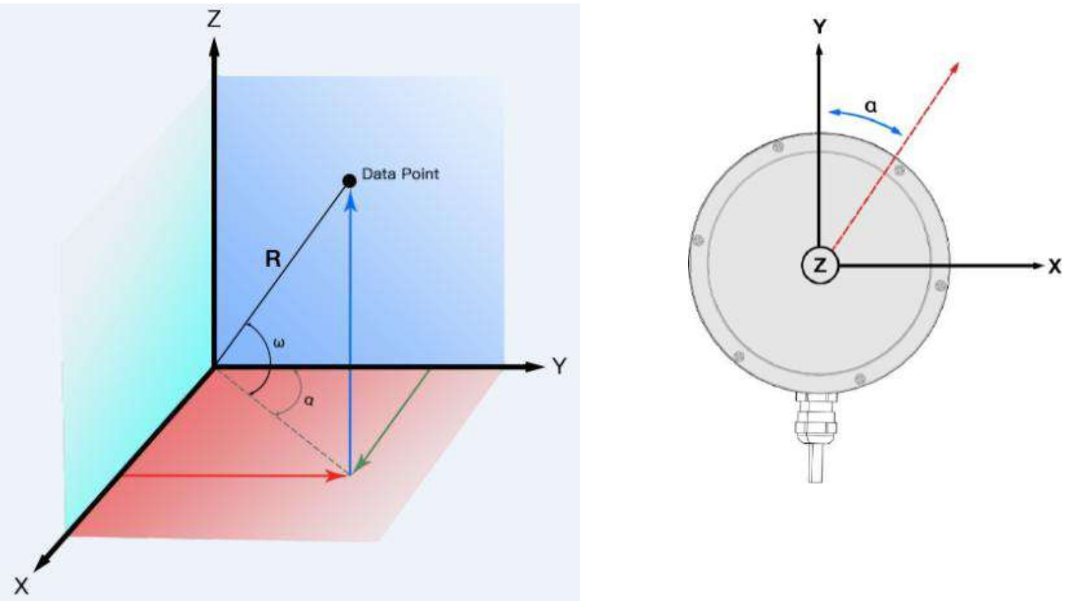


Figure 10: Coordinate system mapping between polar system and XYZ system.

Note 1: In the RS-Bpearl ROS package, the coordinate system must be transferred to the ROS right-hand Coordinate system.

The ROS-X axis is co-axis with the Y-axis and with same direction as Figure 10.

The ROS-Y axis is co-axis with the X-axis but the positive direction is reverse as Figure 10.

The Z axis is same before and after transformation.

Note 2: The origin of the LiDAR coordinate is defined at the center of the LiDAR structure, with 94.27 mm high to the bottom of the LiDAR.

9. Definition of Vertical Angles

RS-Bpearl has a vertical field of view of 90° with a non-uniform distribution. The 32 laser heads also called as 32 channels. The calibrated vertical angle and horizontal angle offset can be found in DIFOP data.

Table 9: Correspondence between Channel No. and vertical Angle.

Channel No.	Vertical Angle	Horizontal Offset Angle
1	89.5	0
2	81.0625	0
3	78.25	0
4	72.625	0
5	67	0
6	61.375	0
7	55.75	0
8	50.125	0
9	86.6875	0
10	83.875	0
11	75.4375	0
12	69.8125	0
13	64.1875	0
14	58.5625	0
15	52.9375	0
16	47.3125	0
17	44.5	0
18	38.875	0
19	33.25	0
20	27.625	0
21	22	0
22	16.375	0
23	10.75	0
24	5.125	0
25	41.6875	0
26	36.0625	0
27	30.4375	0
28	24.8125	0
29	19.1875	0
30	13.5625	0

31	7.9375	0
32	2.3125	0

Every sequence of 32 laser firings consumes 55.5us.

10.Reflectivity

The reflectivity is included in the data field of MSOP packet. Reflectivity is a scale to evaluate the ability of the reflection of light from object. This value is highly related to the material of measured object. Hence, the character can be used to distinguish the different materials.
RS-Bpearl 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.

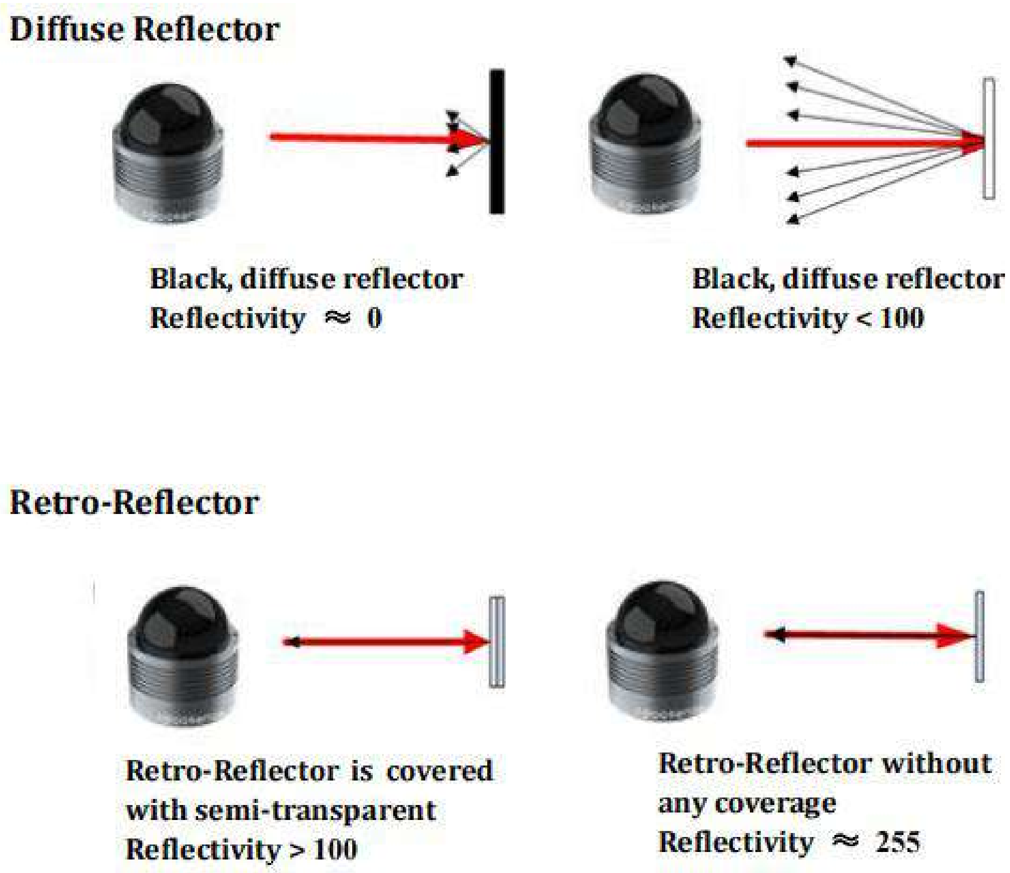


Figure 11: Calibration of Reflectivity.

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 3A @ 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 3A @ 12V) ● Check if the LiDAR mounting plane is level or if the LiDAR bottom fixing screws are too tight.
Unit spins 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 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 receivedby 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 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 configuration
Sensor point cloud data distortion	● Check the configuration files is right
A blank region rotates 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

A.1 RS-Bpearl Calculation of time stamp in single mode

In each MSOP packet, there are 12 blocks, each block has one sequence for the whole 32 laser firings, so in a MSOP packet, there are 12 groups for the whole 32 laser firings. At every firing moment, there are two laser firing together, all 32 lasers are fired and recharged every 55.52 μs. The cycle time between firing is 1.28 μs. 32 firings cost time 32 x 1.28 μs = 40.96 μs. Besides, the charge/recharge time and wait time after emission must be calculated. Therefore, this time interval = 2 * charge time + 2 * recharge time + wait time = 2 * 4.00 us + 2 * 1.20 us + 4.16 us = 14.56 us.

Table A - 1: Time Offset for each Channel in single Return Mode.

channel ID	Data Block											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	55.52	111.04	166.56	222.08	277.60	333.12	388.64	444.16	499.68	555.20	610.72
2	2.56	58.08	113.60	169.12	224.64	280.16	335.68	391.20	446.72	502.24	557.76	613.28
3	5.12	60.64	116.16	171.68	227.20	282.72	338.24	393.76	449.28	504.80	560.32	615.84
4	7.68	63.20	118.72	174.24	229.76	285.28	340.80	396.32	451.84	507.36	562.88	618.40
5	10.24	65.76	121.28	176.80	232.32	287.84	343.36	398.88	454.40	509.92	565.44	620.96
6	12.80	68.32	123.84	179.36	234.88	290.40	345.92	401.44	456.96	512.48	568.00	623.52
7	15.36	70.88	126.40	181.92	237.44	292.96	348.48	404.00	459.52	515.04	570.56	626.08
8	17.92	73.44	128.96	184.48	240.00	295.52	351.04	406.56	462.08	517.60	573.12	628.64
9	25.68	81.20	136.72	192.24	247.76	303.28	358.80	414.32	469.84	525.36	580.88	636.40
10	28.24	83.76	139.28	194.80	250.32	305.84	361.36	416.88	472.40	527.92	583.44	638.96
11	30.80	86.32	141.84	197.36	252.88	308.40	363.92	419.44	474.96	530.48	586.00	641.52
12	33.36	88.88	144.40	199.92	255.44	310.96	366.48	422.00	477.52	533.04	588.56	644.08
13	35.92	91.44	146.96	202.48	258.00	313.52	369.04	424.56	480.08	535.60	591.12	646.64
14	38.48	94.00	149.52	205.04	260.56	316.08	371.60	427.12	482.64	538.16	593.68	649.20
15	41.04	96.56	152.08	207.60	263.12	318.64	374.16	429.68	485.20	540.72	596.24	651.76
16	43.60	99.12	154.64	210.16	265.68	321.20	376.72	432.24	487.76	543.28	598.80	654.32
17	1.28	56.80	112.32	167.84	223.36	278.88	334.40	389.92	445.44	500.96	556.48	612.00
18	3.84	59.36	114.88	170.40	225.92	281.44	336.96	392.48	448.00	503.52	559.04	614.56
19	6.40	61.92	117.44	172.96	228.48	284.00	339.52	395.04	450.56	506.08	561.60	617.12
20	8.96	64.48	120.00	175.52	231.04	286.56	342.08	397.60	453.12	508.64	564.16	619.68
21	11.52	67.04	122.56	178.08	233.60	289.12	344.64	400.16	455.68	511.20	566.72	622.24
22	14.08	69.60	125.12	180.64	236.16	291.68	347.20	402.72	458.24	513.76	569.28	624.80
23	16.64	72.16	127.68	183.20	238.72	294.24	349.76	405.28	460.80	516.32	571.84	627.36
24	19.20	74.72	130.24	185.76	241.28	296.80	352.32	407.84	463.36	518.88	574.40	629.92
25	26.96	82.48	138.00	193.52	249.04	304.56	360.08	415.60	471.12	526.64	582.16	637.68
26	29.52	85.04	140.56	196.08	251.60	307.12	362.64	418.16	473.68	529.20	584.72	640.24
27	32.08	87.60	143.12	198.64	254.16	309.68	365.20	420.72	476.24	531.76	587.28	642.80
28	34.64	90.16	145.68	201.20	256.72	312.24	367.76	423.28	478.80	534.32	589.84	645.36
29	37.20	92.72	148.24	203.76	259.28	314.80	370.32	425.84	481.36	536.88	592.40	647.92
30	39.76	95.28	150.80	206.32	261.84	317.36	372.88	428.40	483.92	539.44	594.96	650.48
31	42.32	97.84	153.36	208.88	264.40	319.92	375.44	430.96	486.48	542.00	597.52	653.04
32	44.88	100.40	155.92	211.44	266.96	322.48	378.00	433.52	489.04	544.56	600.08	655.60

In the firing sequence, Bpearl is first charged once, then the lasers fire one by one from channel 1 to channel 8 and from channel 17 to channel 24 respectively. After that, Laser emitters are charged once again, then lasers fire from Channel 9 to channel 16 and from channel 25 to channel32 respectively.

Set the channel number data_index is 1~32, sequence_index is 1~12. 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:

Formal for Calculation of Time_offset from Channel 1 to channel 8 and from channel 17 to channel 24:
Time_offset = 55.52 * (sequence_index - 1) + 2.56 * mod((data_index – 1) , 16) + 1.28 * floor((data_index-1) / 16)

Formal for Calculation of Time_offset from Channel 9 to channel 16 and from channel 25 to channel 32：
Time_offset = 55.52 * (sequence_index - 1) + 2.56 * mod((data_index – 1) , 16) + 1.28 * floor((data_index-1) / 16) + 5.2

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

Exact_point _time = Timestamp + Time_offset

A.2 RS-Bpearl Calculation of time stamp in dual mode

In dual mode, for each MSOP packet, there are 12 blocks. Each two block has one sequence for the whole 32 laser firings, e.g. Block 1 and Block 2 are two captured return signals after all 32 laser emitting once, Block 1 is the strongest return signal, block 2 is the second strongest return signal.
Set the channel number data_index is 1~32, sequence_index is 1~12. 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.

Table A - 2. Time Offset for Each Channel in dual return mode.

channel ID	Data Block											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	0.00	55.52	55.52	111.04	111.04	166.56	166.56	222.08	222.08	277.60	277.60
2	2.56	2.56	58.08	58.08	113.60	113.60	169.12	169.12	224.64	224.64	280.16	280.16
3	5.12	5.12	60.64	60.64	116.16	116.16	171.68	171.68	227.20	227.20	282.72	282.72
4	7.68	7.68	63.20	63.20	118.72	118.72	174.24	174.24	229.76	229.76	285.28	285.28
5	10.24	10.24	65.76	65.76	121.28	121.28	176.80	176.80	232.32	232.32	287.84	287.84
6	12.80	12.80	68.32	68.32	123.84	123.84	179.36	179.36	234.88	234.88	290.40	290.40
7	15.36	15.36	70.88	70.88	126.40	126.40	181.92	181.92	237.44	237.44	292.96	292.96
8	17.92	17.92	73.44	73.44	128.96	128.96	184.48	184.48	240.00	240.00	295.52	295.52
9	25.68	25.68	81.20	81.20	136.72	136.72	192.24	192.24	247.76	247.76	303.28	303.28
10	28.24	28.24	83.76	83.76	139.28	139.28	194.80	194.80	250.32	250.32	305.84	305.84
11	30.80	30.80	86.32	86.32	141.84	141.84	197.36	197.36	252.88	252.88	308.40	308.40
12	33.36	33.36	88.88	88.88	144.40	144.40	199.92	199.92	255.44	255.44	310.96	310.96
13	35.92	35.92	91.44	91.44	146.96	146.96	202.48	202.48	258.00	258.00	313.52	313.52
14	38.48	38.48	94.00	94.00	149.52	149.52	205.04	205.04	260.56	260.56	316.08	316.08
15	41.04	41.04	96.56	96.56	152.08	152.08	207.60	207.60	263.12	263.12	318.64	318.64
16	43.60	43.60	99.12	99.12	154.64	154.64	210.16	210.16	265.68	265.68	321.20	321.20
17	1.28	1.28	56.80	56.80	112.32	112.32	167.84	167.84	223.36	223.36	278.88	278.88
18	3.84	3.84	59.36	59.36	114.88	114.88	170.40	170.40	225.92	225.92	281.44	281.44
19	6.40	6.40	61.92	61.92	117.44	117.44	172.96	172.96	228.48	228.48	284.00	284.00
20	8.96	8.96	64.48	64.48	120.00	120.00	175.52	175.52	231.04	231.04	286.56	286.56
21	11.52	11.52	67.04	67.04	122.56	122.56	178.08	178.08	233.60	233.60	289.12	289.12
22	14.08	14.08	69.60	69.60	125.12	125.12	180.64	180.64	236.16	236.16	291.68	291.68
23	16.64	16.64	72.16	72.16	127.68	127.68	183.20	183.20	238.72	238.72	294.24	294.24
24	19.20	19.20	74.72	74.72	130.24	130.24	185.76	185.76	241.28	241.28	296.80	296.80
25	26.96	26.96	82.48	82.48	138.00	138.00	193.52	193.52	249.04	249.04	304.56	304.56
26	29.52	29.52	85.04	85.04	140.56	140.56	196.08	196.08	251.60	251.60	307.12	307.12
27	32.08	32.08	87.60	87.60	143.12	143.12	198.64	198.64	254.16	254.16	309.68	309.68
28	34.64	34.64	90.16	90.16	145.68	145.68	201.20	201.20	256.72	256.72	312.24	312.24
29	37.20	37.20	92.72	92.72	148.24	148.24	203.76	203.76	259.28	259.28	314.80	314.80
30	39.76	39.76	95.28	95.28	150.80	150.80	206.32	206.32	261.84	261.84	317.36	317.36
31	42.32	42.32	97.84	97.84	153.36	153.36	208.88	208.88	264.40	264.40	319.92	319.92
32	44.88	44.88	100.40	100.40	155.92	155.92	211.44	211.44	266.96	266.96	322.48	322.48

Time_offset is:
Formal for Calculation of Time_offset from Channel 1 to channel 8 and from channel 17 to channel 24:
Time_offset = 55.52 * (floor ((sequence_index - 1) /2)) + 2.56 * mod((data_index – 1) , 16)
+ 1.28 * floor((data_index-1) / 16)

Formal for Calculation of Time_offset from Channel 9 to channel 16 and from channel 25 to channel 32：
Time_offset = 55.52 * (floor ((sequence_index - 1) /2)) + 2.56 * mod((data_index – 1) , 16)
+ 1.28 * floor((data_index-1) / 16) + 5.2

To calculate the exact point time (Exact_point _time), add the Time_Offset to the timestamp:

Exact_point _time = Timestamp + Time_offset

Note:

mod is an operator that divides two numbers and returns only the remainder.
floor is a function that returns an integer less than the argument or equal to it.

Appendix B Information Registers

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

B.1 Motor(MOT_SPD)

Motor Speed (2 bytes in total)						
Byte No.	byte1	byte2				
Function	MOTOR_SPD					

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 the value of rotation with other data, the rotation speed of the motor is 0.

B.2 Ethernet(ETH)

Ethernet (26 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~port6 signals the number of ports. Port1 and port2 are the MSOP packet ports, we suggested to set them to the same number. Port3 and port4 are the DIFOP packet ports, we suggested to set them to the same number.

B.3 FOV Setting (FOV SET)

FOV Setting(Total 4bytes)						
Byte 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:
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)

Motor Phase Offset(2bytes in total)						
Byte 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 Board Firmware(5bytes in total)						
Byte 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 A0,0x06230606A0.
In the output, the A represents release version Application, while the F represents factory version Factory.

B.6 Bottom Board Firmware (BOT_FRM)

Bottom Board Firmware(5bytes in total)						
Byte 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 06 23 06 06 F0. In the output, the A represent release version Application, while the F represent factory version Factory.

B.7 Serial Number(SN)

Serial Number(6 bytes in total)						
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6
Function	SN					

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

B.8 Software Version(SOFTWARE_VER)

Software Version(2 bytes in total)						
Byte No.	byte1	byte2				
Function	SOFTWARE_VER					

B.9 UTC Time(UTC_TIME)

UTC Time (8 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

reg name：set_us								
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_us[7:0]							

Note：set_us[9:0] value：0~999

B.10 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 1μA, the formula is as below:

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

For example, if byte1 = 8C, byte2 = D5 and byte3 = 00, then the current value is:

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

(2) There are six different voltages, 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.11 Fault Diagnosis

Fault Diagnosis (40bytes in total)								
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8
Function	internal debug							
Byte No.	byte9	byte10	byte11	byte12	byte13	byte14	byte15	byte16
Function	internal debug		cksum_st	manc_err1		manc_err2		gps_st
Byte No.	byte17	byte18	byte19	byte20	byte21	byte22	byte23	byte24
Function	temperature1		temperature2		temperature3		temperature4	
Byte No.	byte25	byte26	byte27	byte28	byte29	byte30	byte31	byte32
Function	temperature5		internal debug					r_rpm1
Byte No.	byte33	byte34	byte35	byte36	byte37	byte38	byte39	byte40
Function	r_rpm2	internal debug						

Register description:

(1) chksum_st represents the temperature compensation status. If chksum_st = 0x00, the temperature compensation is working. If chksum_st = 0x01, 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 the manc_err1_per and manc_err1_per are both 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 bits to describe the validation for PPS, GPRMC, and timestamp. The details are shown below:

GPS input status register GPS_ST			
BIT	Function	Value	Status
bit0	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	0	LiDAR internal timestamp is not synchronizing the UTC.
		1	LiDAR internal timestamp is synchronizing the UTC.
bit3~bit7	Reserved	x	N/A

(1) 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

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

B.12 ASCII code in GPRMC Packet

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

B.13 Corrected Vertical Angle (COR_VERT_ANG)

Corrected Vertical Angle（96bytes in total）									
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8	byte9
Function	Channel 1_COR_VERT_ANG			Channel 2_COR_VERT_ANG			Channel 3_COR_VERT_ANG		
Byte No.	byte10	byte11	byte12	byte13	byte14	byte15	byte16	byte17	byte18
Function	Channel 4_COR_VERT_ANG			Channel 5_COR_VERT_ANG			Channel 6_COR_VERT_ANG		
Byte No.	byte19	byte20	byte21	byte22	byte23	byte24	byte25	byte26	byte27
Function	Channel 7_COR_VERT_ANG			Channel 8_COR_VERT_ANG			Channel 9_COR_VERT_ANG		
Byte No.	byte28	byte29	byte30	byte31	byte32	byte33	byte34	byte35	byte36
Function	Channel 10_COR_VERT_ANG			Channel 11_COR_VERT_ANG			Channel 12_COR_VERT_ANG		
Byte No.	byte37	byte38	byte39	byte40	byte41	byte42	byte43	byte44	byte45
Function	Channel 13_COR_VERT_ANG			Channel 14_COR_VERT_ANG			Channel 15_COR_VERT_ANG		
Byte No.	byte46	byte47	byte48	byte49	byte50	byte51	byte52	byte53	byte54
Function	Channel 16_COR_VERT_ANG			Channel 17_COR_VERT_ANG			Channel 18_COR_VERT_ANG		
Byte No.	byte55	byte56	byte57	byte58	byte59	byte60	byte61	byte62	byte63
Function	Channel 19_COR_VERT_ANG			Channel 20_COR_VERT_ANG			Channel 21_COR_VERT_ANG		
Byte No.	byte64	byte65	byte66	byte67	byte68	byte69	byte70	byte71	byte72
Function	Channel 22_COR_VERT_ANG			Channel 23_COR_VERT_ANG			Channel 24_COR_VERT_ANG		
Byte No.	byte73	byte74	byte75	byte76	byte77	byte78	byte79	byte80	byte81
Function	Channel 25_COR_VERT_ANG			Channel 26_COR_VERT_ANG			Channel 27_COR_VERT_ANG		
Byte No.	byte82	byte83	byte84	byte85	byte86	byte87	byte88	byte89	byte90
Function	Channel 28_COR_VERT_ANG			Channel 29_COR_VERT_ANG			Channel 30_COR_VERT_ANG		
Byte No.	byte91	byte92	byte93	byte94	byte95	byte96			
Function	Channel 31_COR_VERT_ANG			Channel 32_COR_VERT_ANG					

Register description:

(1) The angle value is signed integer, vertical angle for each channel is consist of 3 bytes, while the first byte represents the sign, the second byte and the third byte represent the value for the angle, storage mode is Big-endian.

(2) The first byte 0x00 represents positive while 0x01 represents negative.

(3) LSB=0.01º.

For example the register for vertical angle of Channel 1is as below: byte1=0x00, byte2=0x22 convert to decimal is 34, byte3=0XF6 convert to decimal is 246, so the vertical angle of Channel 1 is：

(34*256+ 246) *0.01º = 89.50º

B.14 Corrected Horizontal Offset Angle (COR_HOR_ANG)

Corrected horizontal Angle（96bytes in total）									
Byte No.	byte1	byte2	byte3	byte4	byte5	byte6	byte7	byte8	byte9
Function	Channel 1_COR_HOR_ANG			Channel 2_COR_HOR_ANG			Channel 3_COR_HOR_ANG		
Byte No.	byte10	byte11	byte12	byte13	byte14	byte15	byte16	byte17	byte18
Function	Channel 4_COR_HOR_ANG			Channel 5_COR_HOR_ANG			Channel 6_COR_HOR_ANG		
Byte No.	byte19	byte20	byte21	byte22	byte23	byte24	byte25	byte26	byte27
Function	Channel 7_COR_HOR_ANG			Channel 8_COR_HOR_ANG			Channel 9_COR_HOR_ANG		
Byte No.	byte28	byte29	byte30	byte31	byte32	byte33	byte34	byte35	byte36
Function	Channel 10_COR_HOR_ANG			Channel 11_COR_HOR_ANG			Channel 12_COR_HOR_ANG		
Byte No.	byte37	byte38	byte39	byte40	byte41	byte42	byte43	byte44	byte45
Function	Channel 13_COR_HOR_ANG			Channel 14_COR_HOR_ANG			Channel 15_COR_HOR_ANG		
Byte No.	byte46	byte47	byte48	byte49	byte50	byte51	byte52	byte53	byte54
Function	Channel 16_COR_HOR_ANG			Channel 17_COR_HOR_ANG			Channel 18_COR_HOR_ANG		
Byte No.	byte55	byte56	byte57	byte58	byte59	byte60	byte61	byte62	byte63
Function	Channel 19_COR_HOR_ANG			Channel 20_COR_HOR_ANG			Channel 21_COR_HOR_ANG		
Byte No.	byte64	byte65	byte66	byte67	byte68	byte69	byte70	byte71	byte72
Function	Channel 22_COR_HOR_ANG			Channel 23_COR_HOR_ANG			Channel 24_COR_HOR_ANG		
Byte No.	byte73	byte74	byte75	byte76	byte77	byte78	byte79	byte80	byte81
Function	Channel 25_COR_HOR_ANG			Channel 26_COR_HOR_ANG			Channel 27_COR_HOR_ANG		
Byte No.	byte82	byte83	byte84	byte85	byte86	byte87	byte88	byte89	byte90
Function	Channel 28_COR_HOR_ANG			Channel 29_COR_HOR_ANG			Channel 30_COR_HOR_ANG		
Byte No.	byte91	byte92	byte93	byte94	byte95	byte96			
Function	Channel 31_COR_HOR_ANG			Channel 32_COR_HOR_ANG					

Register description ：

(1) The angle value is signed integer, vertical angle for each channel is consist of 3 bytes, while the first byte represents the sign, the second byte and the third byte represent the value for the angle.

(2) The first byte 0x00 represents positive while 0x01 represents negative.

(3) LSB=0.01º;

For example the register for vertical angle of Channel 10 is as below: byte1=0x01, byte2=0x00 convert to decimal is 0, byte3=0x0A convert to decimal is 10, so the vertical angle of Channel 10 is：

-(0*256+ 10) *0.01=-0.1º

Appendix C RSView

In this appendix, the record, visualization, save and redisplay of the data from RS-Bpearl will be interpreted with using RSView. The original sensor data can be also captured and examined by using other free tools, such as Wireshark or TCP-Dump. But visualization of the 3D data through using RSView is easy to realize. RS-Bpearl is used with RSView vision 3.1.5. or above

C.1 Software Features

RSView can provide real-time visualization of 3D coordinate data from RS-Bpearl. RSView can also review the pre-recorded data stored in "pcap" (Packet Capture) files, but RSView still doesn't support directly importing ".pcapng" files.
RSView displays directly the point cloud that is exchanged from the measured distance from RS-Bpearl. It supports changing the display mode of point cloud as user wishes, according to Reflectivity, timestamp, distance, azimuth, and laser channel. The data can be exported as XYZ coordinate data in CSV format or LAS format. RSView does not support generating point cloud files in XYZ, or PLY formats.
Function and features of RSView are shown as follow:

- Online visualization of sensor data over Ethernet
- Record of real-time data into pcap files
- Review of the collected point cloud from pcap files
- Different visualization mode based on distance, timestamp, azimuth, laser ID, etc.
- Tabular inspection of point cloud data
- Exporting the point cloud data into CSV format
- Tool for measuring distance from visualized cloud point
- Simultaneously Display of multiple continuous frames (Trailing frames)
- Display or hide subsets of lasers
- Crop tool to show partial point cloud

C.2 Installation of RSView

Installation packet of RSView is suited for Windows 64-bit system and it has no need for other dependent software packets.
The latest version of executable installation packet can be found from RoboSense website (http://www.robosense.ai/resource). Launch the installation packet and follow the instructions to complete the installation. The installation path should not contain any Chinese characters.

C.3 Network Setup

As mentioned in the chapter 5, 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 RSView doesn't be blocked by firewall in PC.

C.4 Visualization of point cloud

1. Connect the RS-Bpearl to PC over Ethernet cables and power supply.

2. Right Click to start the RSView application with Run as administrator.
3. Click on the **"File"-> Open -> Sensor Stream** (Fig. C-1).

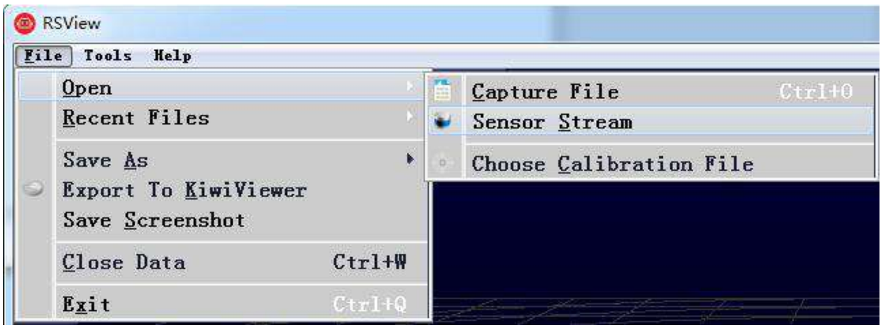


Figure C - 1: Open sensor stream in RSView.

4. After finishing above 3 steps, the dialogue box **"Sensor Configuration"** shows up. In this dialogue box, the default configuration folder of RS-Bpearl calibration is already contained and the folder is already chosen. In "Type of LiDAR", the option **RSBpearl** should be chosen, in "**Intensity**", **Mode3** should be chosen. Finally, click **"OK"** (as shown in Fig. C-2).

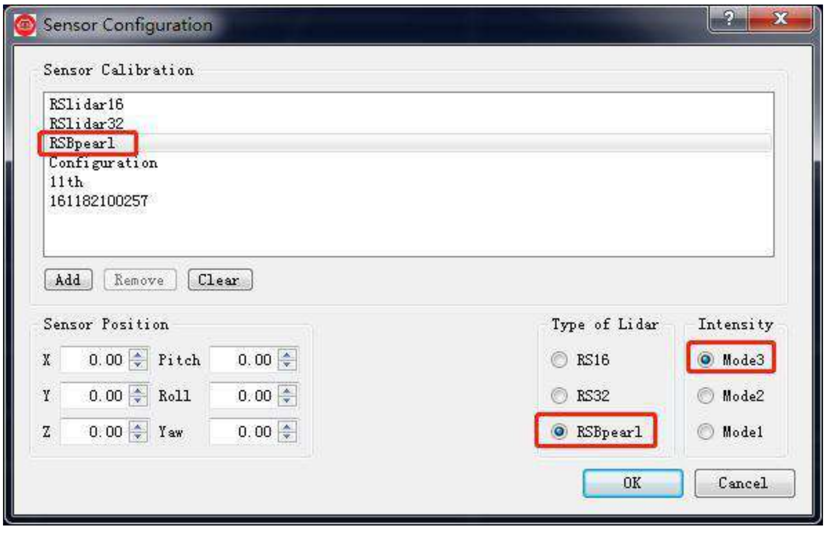


Figure C - 2: RSView Select Sensor Correction File.

RSView begins displaying the colored point cloud from capturing the sensor data stream from LiDAR (as shown in Fig. C-3). The stream can be paused by pressing the **"Play/Pause"** button.

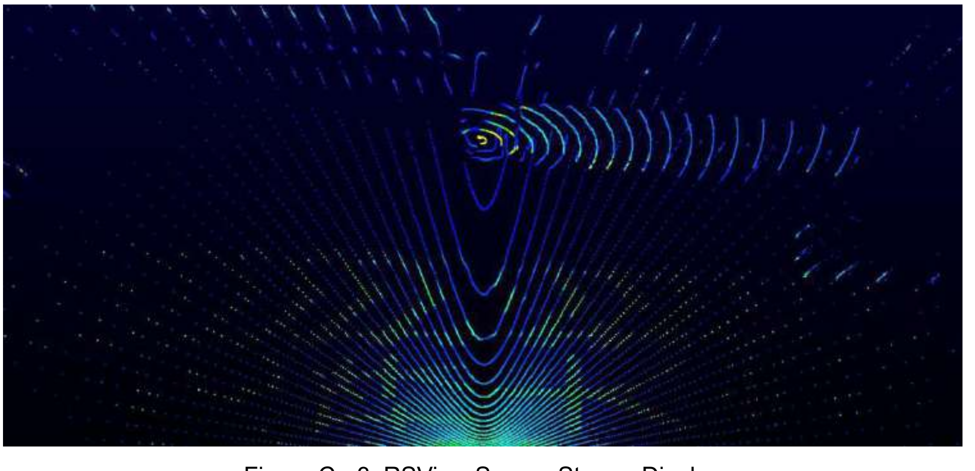


Figure C - 3: RSView Sensor Stream Display.

C.5 Save Streaming Sensor Data into PCAP File

1. Click the **“Record”** button while real-time display (Fig. C-4).

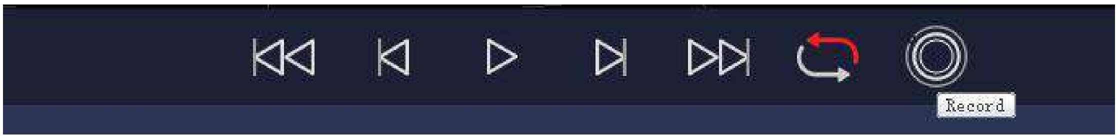


Figure C - 4: RSView Record Button.

2. In the dialogue box **Choose Output File**, the save path and file name of pcap file can be set up. (Fig. C-5). After clicking “save” button, RSView begins writing data into pcap file. (Note: RS-Bpearl will generate enormous measuring data. So, it is best to use a fast, local HDD or SSD, not to use a slow subsystem such as USB storage device or network drive.)

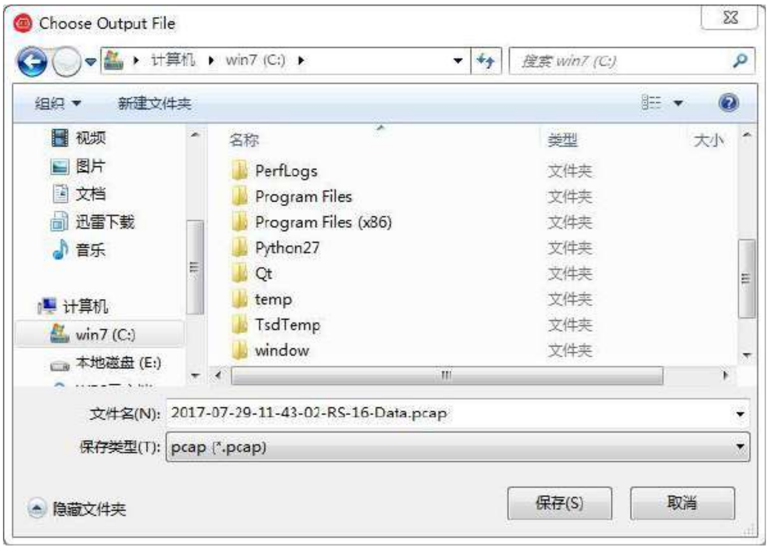


Figure C - 5: RSView Record Saving Dialog.

3. Click **“Record”** Button will finish record and save the all recorded data into this pcap file.

C.6 Replay Recorded Sensor Data from PCAP Files

In order to replaying (or examining) a pcap file, please import it into RSView. Then press **“Play/Pause”** button to let it play or scrub the time slider to a certain time point as user wishes. When only a part of 3D point cloud is concerned, it can be selected out by mouse. Then point cloud data of this part can be shown in table. Save path of pcap file can’t contain Chinese characters.

1. Click **File -> Open** then select **Capture File**.

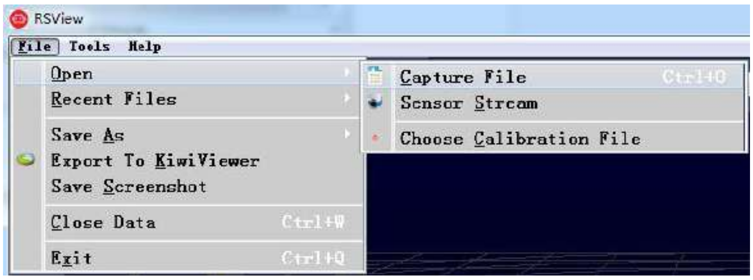


Figure C - 6: RSView Open Capture File.

2. In dialogue box “Open File”, please import a recorded pcap file then click “open (O)”

button.

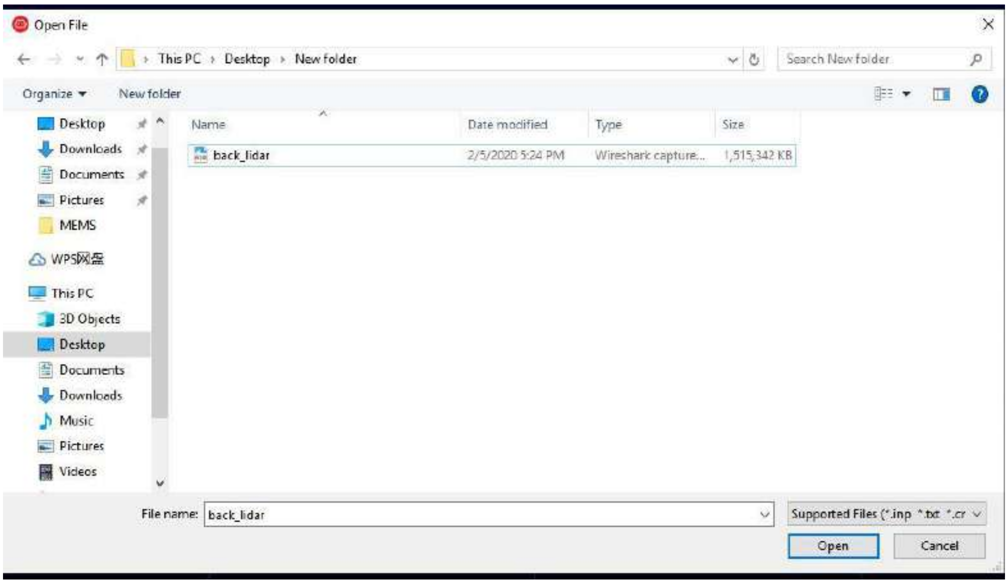


Figure C - 7: Select the PCAP File.

3. In dialogue box **Sensor Configuration**, please add and select the right configuration file of RS-Bpearl, then click **OK**.

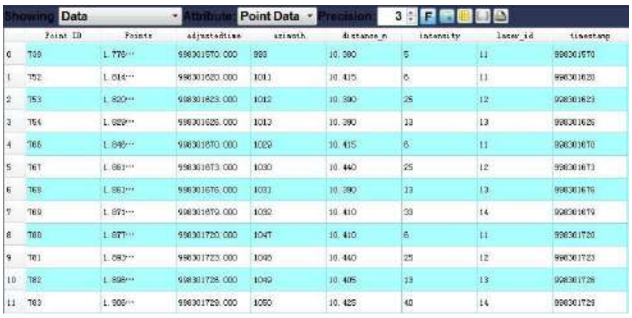
4. Clicking **"Play/Pause"** button can make 3D point cloud stream play and pause. Using the **Scrub** tool can select out the interesting frame. (Fig. C-8)

Figure C - 8: RSView Play Button and Scrub slide tool.

5. In order to inspecting partial relevant point cloud data from a closer aspect, please scrub to an interesting frame and click the Spreadsheet button (Fig. C-9). A data table will be displayed on the right side. It contains all displayed data points in the frame.

Figure C - 9: RSView Spreadsheet tool.

6. The dimension and the sort of data in this table are adjustable. That can make the display more obvious. (Fig. C -10)



Showing: Data Attribute: Point Data Precision: 3

	Point ID	Points	adjustedtime	azimuth	distance_m	intensity	laser_id	timestamp
0	738	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	33	13	998301626
4	766	1.846···	998301670.000	1029	10.415	8	11	998301670
5	767	1.861···	998301673.000	1030	10.440	25	12	998301673
6	768	1.863···	998301676.000	1031	10.390	33	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	1.883···	998301723.000	1048	10.440	25	12	998301723
10	782	1.898···	998301726.000	1049	10.405	33	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 spreadsheet can acquire corresponding data, certainly there is no data shown in table, if no one point is selected. (Fig.C -11)

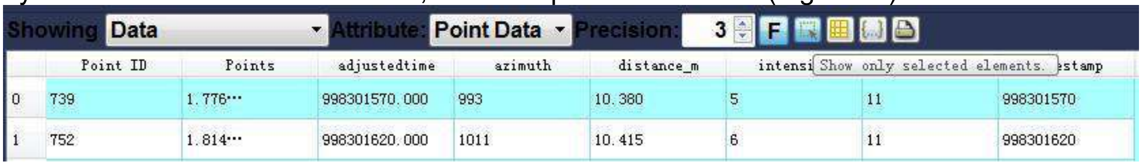


Figure C - 11: RSView Show Only Selected Elements.

8. By using **"Select All Points"** Tool, the arbitrary point can be selected. (as shown in Fig. C -12)

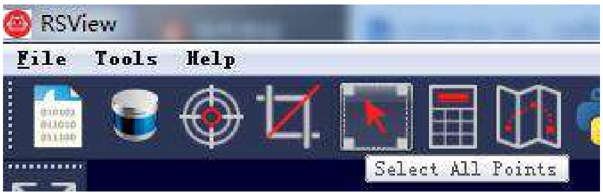


Figure C - 12: RSView Select All Points.

In the 3D rendered data pane using mouse to draw a rectangle around a small number of points. The values of them can be immediately shown in the table (Fig. C-13).

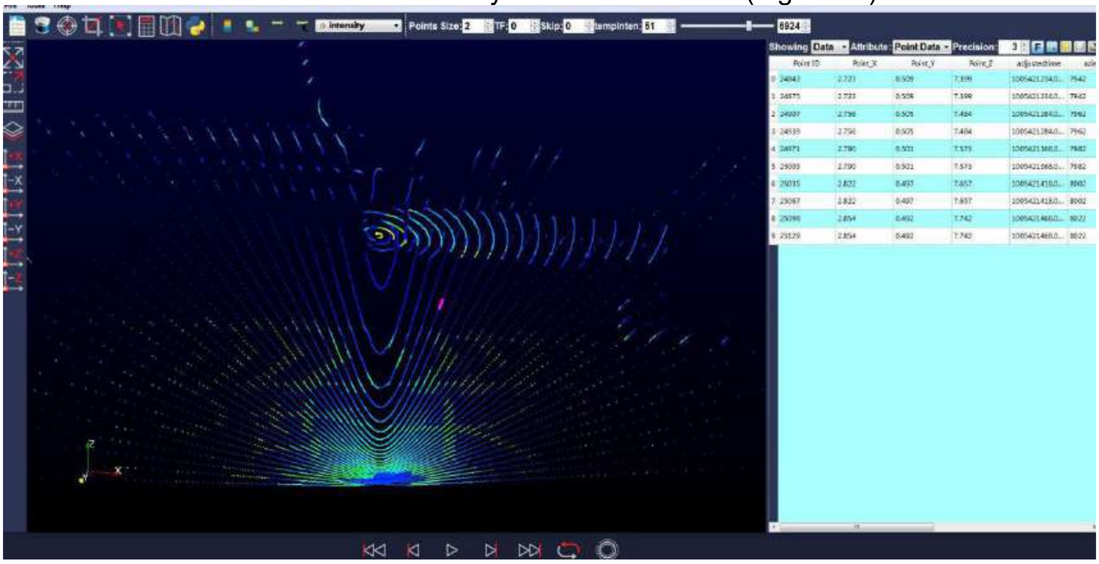


Figure C - 13: RSView Selected Points.

9. Any selected point can be saved by doing **File->Save As->Select** Frames.

C.7 RS-Bpearl Factory Firmware Parameters Setting

RSView supplies a tool which integrates UCWP Protocol. It can be used to modify Rotate Speed, Network, Time, FOV and return mode in RS-Bpearl factory firmware.

Before setting the firmware parameters, please ensure the connectivity of the RS-Bpearl and Display of real-time point cloud. Then Click **Tools > RS-LiDAR Information**, next, in **RS-LiDAR Information** dialogue, click **"Get"** button, the current firmware parameters setting will be shown in this dialogue.

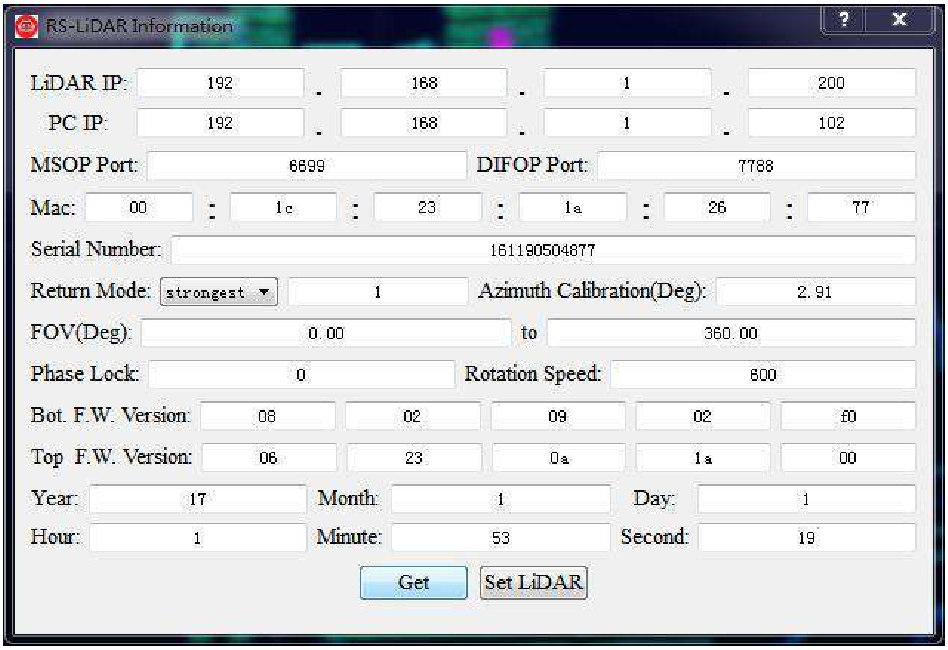


Figure C – 14: RS-LiDAR Information.

After modifying the values of parameters, click **"Set LiDAR"**, the Parameter will be set to what user needs (the red marks in Figure C-15 are only an example, it shows a possibility for parameter change). Then wait 10 seconds, restart RS-Bpearl, wait for device connected, open the RSView to check, whether parameters have been changed.

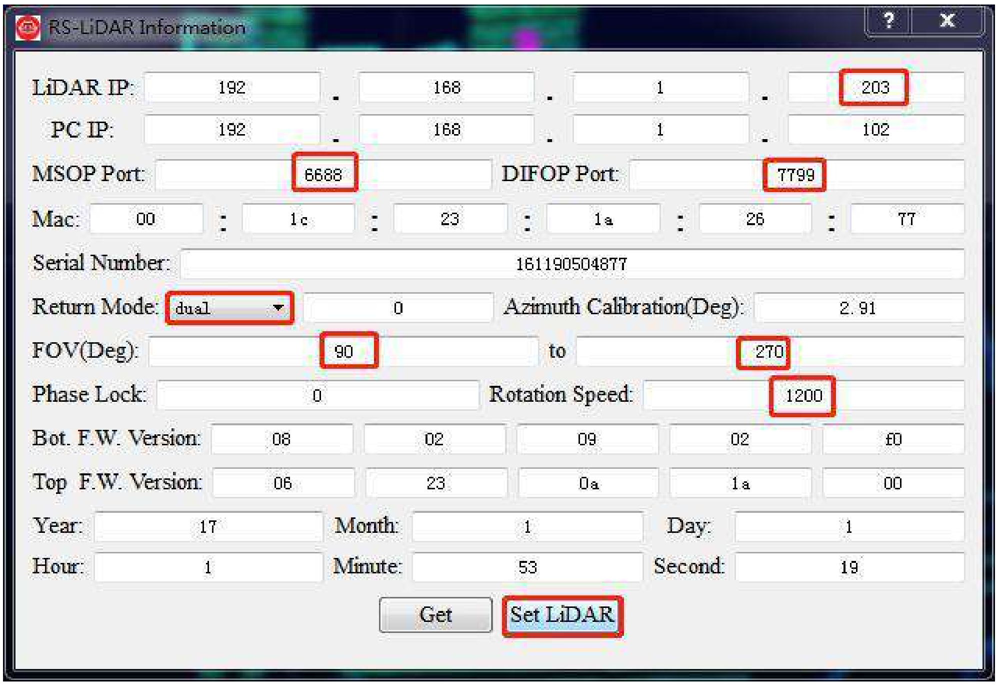


Figure C-15: Set LiDAR information.

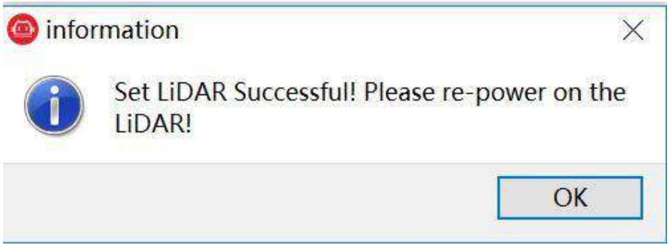


Figure C – 16: Set LiDAR information successful.

Note 1: during the process of parameter setting, please not cut off the power supply. Otherwise, the internal parameters in LiDAR will be incorrectly saved.
Note 2: if the MSOP Port or the DIFOP Port is modified, please set the Data Port in RSView first according to following section C.8 before reconnecting device.

C.8 Setting RSView Data Port

The MSOP Port by default is 6699, and the DIFOP Port is 7788. If one of the two parameters or both of them has been changed (just like the description in section C-7), the new Data Port in RSView must be set and refreshed. Otherwise, the data won't be displayed. If the MSOP Port and DIFOP Port in RS-Bpearl are unknown or forgotten, user can utilize the software Wireshark to capture the data packet from Dst Port.
Click Tools > Data Port, type the MSOP Port and the DIFOP Port changed, then click Set Data Port.

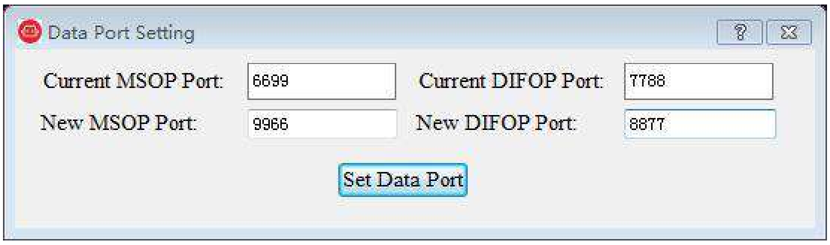


Figure C-17: Set Data Port.

C.9 Firmware Update Online

Please ensure the connectivity of LiDAR, and point cloud can be displayed and get the firmware information according to section C.8.
Click Tools > Online Update, as shown in Figure C-18, top board update and bottom board update could be selected.

Figure C-18: Online Update.

For example, click Bottom Board Update, then choose the proper firmware file with suffix ".rpd", then click open, start Bottom Board Update. The update process will take a while, after update "Online Update Successful" will be shown in a message box.
Note: Config Updata is not available.

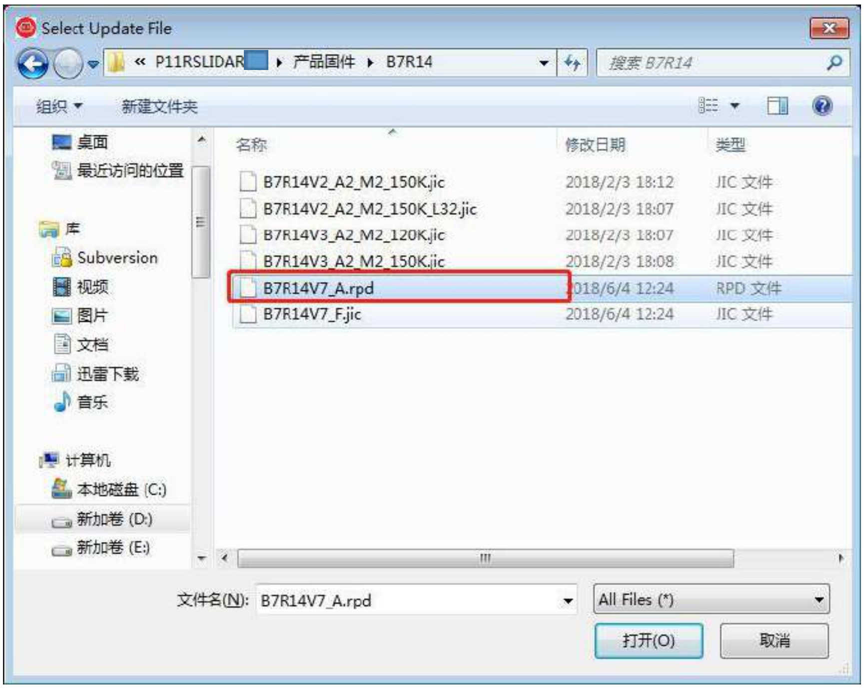


Figure C-19: select update firmware.

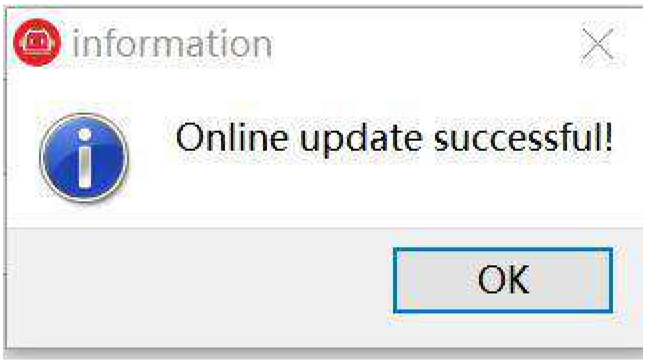


Figure C-20: Online Update successfully.

C.10 Troubleshooting by Fault Diagnosis

Firstly, need to check connectivity of RS-Bpearl, point cloud can be displayed normally and the Firmware information (as shown in section C.8) can be got.
Click **Tools > Fault Diagnosis**, Fault diagnosis window will be shown. Click **"Start"** button, the conformance of RS-Bpearl can be real-time monitored, the parameter including current, voltage, temperature, Uart Baund Error and so on.

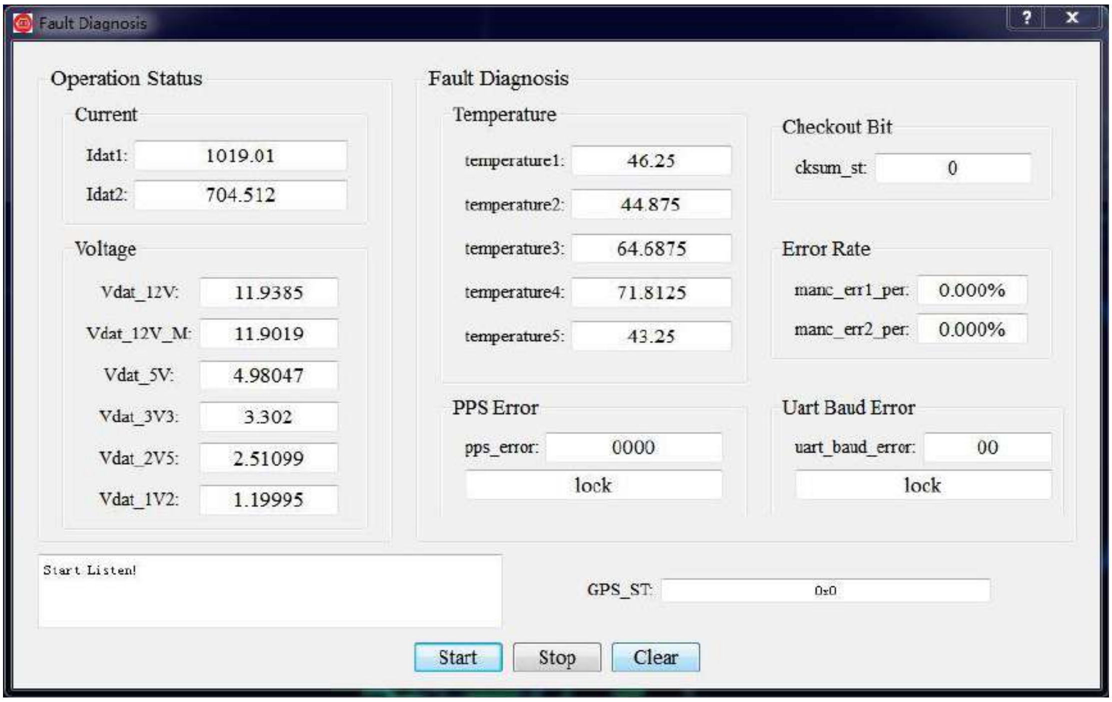


Figure C-21: Fault Diagnosis Dialogue.

Appendix D RS-Bpearl ROS Package

This appendix describes how to use Ubuntu + ROS to acquiring and visualizing the measuring data from RS-Bpearl.

D.1 Software Installation

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

D.2 Compile RS-Bpearl ROS Package

1. Create a workspace for ROS:

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

2. Copy the corresponding ros_rslidar_package into the ROS workspace under the path: ~/catkin_ws/src. The latest ros_rslidar driver can be downloaded from https://github.com/RoboSense-LiDAR/ros_rslidar or contact Robosense support.
3. Build：

```
cd ~/catkin_ws
catkin_make
```

4. Place the configuration file of corresponding LiDAR into PC:
5. At present, configuration files have been written in LiDAR. If not, use the configuration files by default in ROS-Driver. Meanwhile, update the parameter in launch file. This path of launch file can be customized.
6. For example: rslidar_pointcloud/data/rs_Bpearl
7. Note: If user needs to modify the code, relevant code files could not be read.

D.3 Configure PC IP address

For the default RS-Bpearl firmware, static IP address of PC is configured to "192.168.1.102", submask: "255.255.255.0", gateway doesn't need to configure.
After configuring the static IP, it can be examined in CMD with code ifconfig.

D.4 Display of the real-time data

1. Connect the RS-Bpearl to PC via twister pair wire with RJ45 connector, power on it, then wait for PC cognizing LiDAR.
2. An example launch file has been provided under path: rslidar_pointcloud/launch, in order to starting the node that can be run to visualize the real-time point cloud data. Open a terminal with a location as shown as below:

```
cd ~/catkin_ws
source devel/setup.bash
roslaunch rslidar_pointcloud rs_Bpearl.launch
```

3. Open a new terminal:

```
rviz
```

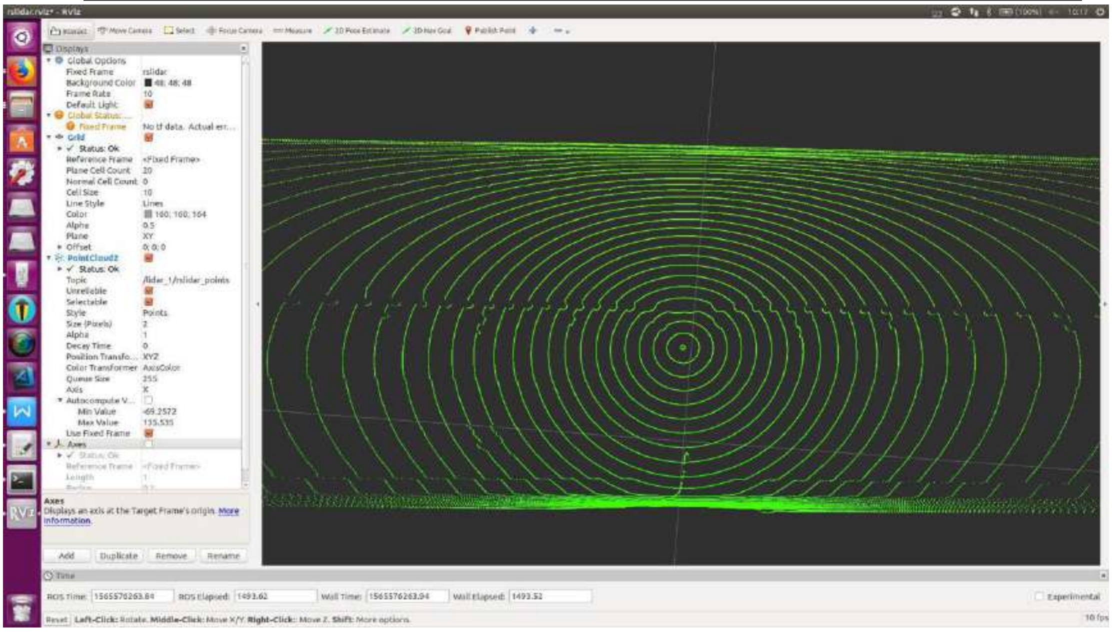


Figure D - 1. Display point cloud Data in Rviz.

D.5 Offline Display the recorded PCAP File

The ros_rslidar ROS package can be also use to display the recorded. Pcap offline data.

1. Modify the “rs_Bpearl.launch” file like below (please pay attention to the red code line):

```
<launch>
  <arg name="model" default="RS-BPearl" />
  <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_Bpearl/"/>

  <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="指向.pcap 的绝对路径"/>
  </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 the node:

```
cd ~/catkin_ws
source devel/setup.bash
roslaunch rslidar_pointcloud rs_lidar_Bpearl.launch
```

3. This step is same as step 3 in section C.4.

Appendix E Dimension

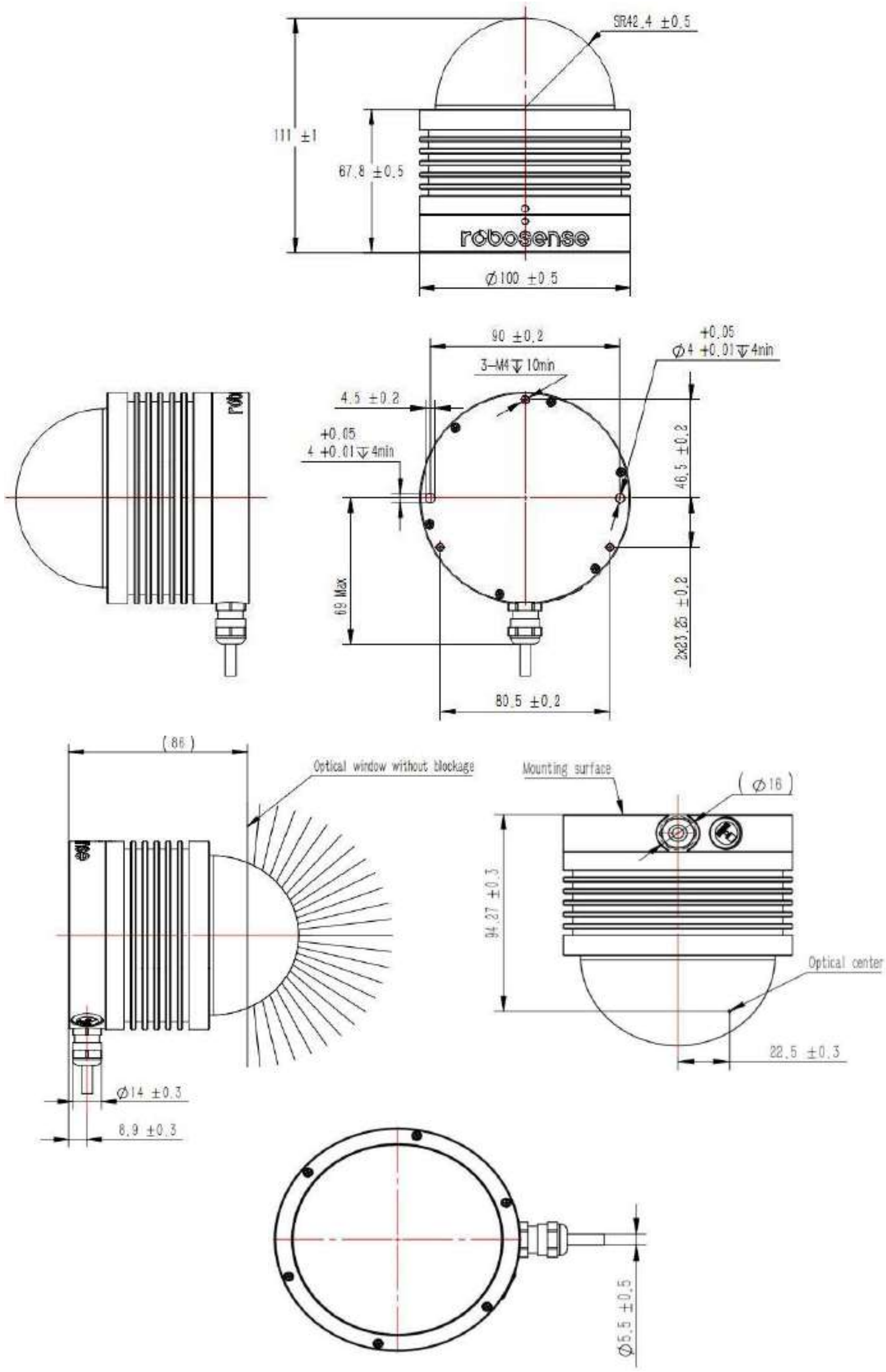


Figure E - 1. Dimension Drawing of RS-LiDAR-Bpearl.

Appendix F Suggestion of Mechanical LiDAR Mount

Please make sure the surface of platform used for mounting 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 mounting contact 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.
When the LiDAR cable is routed in the mount device, please keep the cable a little slack, not too tense.

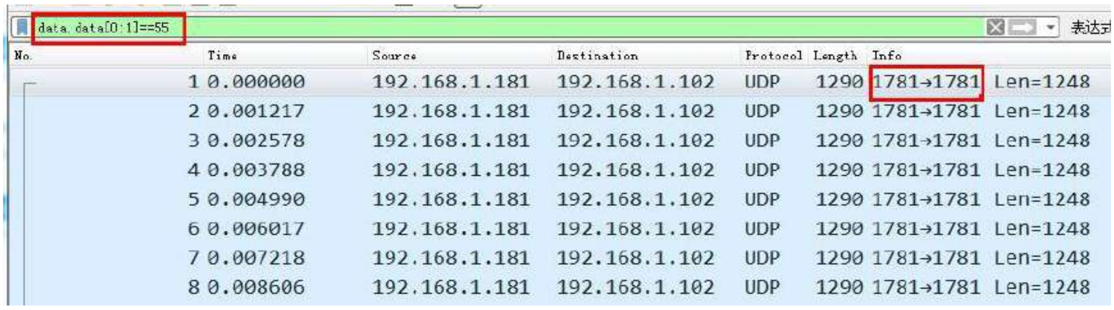
Appendix G Seek MSOP and DIFOP Port Number

According to the description of chapter 5, MSOP and DISOP are the two protocols can be sent out by RS-Bpearl. Their content could be parsed from excepted port by wireshark that is a network protocol analyzer. The port information can be used to set up the Data Port in RSView.

The steps of wireshark usage to set up the right port number for RSView:

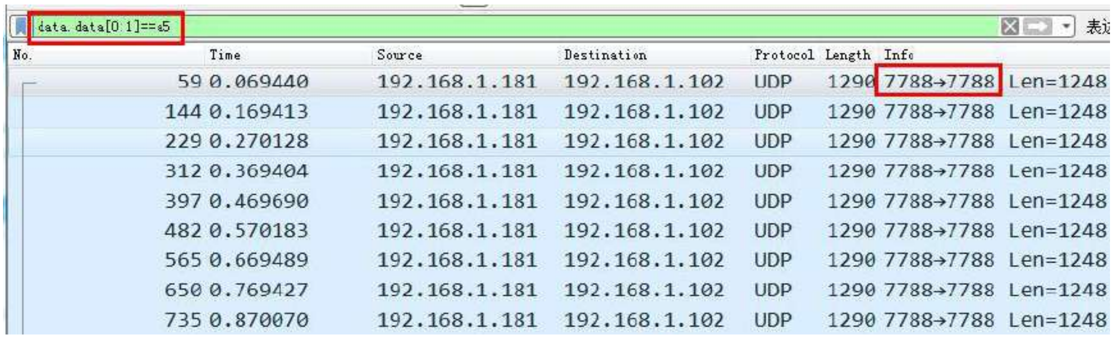
Connect LiDAR to PC and power supply to it. Open wireshark software, choose the corresponding Ethernet port, start to capture packet from LiDAR sending. Type filter condition “**data.data[0:1]==55**” into the display filter (Hot key: Ctrl + /). Then the MSOP packet can be filtered out. The MSOP port number can be checked in info column, as shown in Figure G-1.

For DIFOP port number checking, all of the steps are same except the step of typing filter condition with “**data.data[0:1]==a5**” , as shown in Figure G-2.


data.data[0:1]==55

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 Filtering Out MSOP Port Number.


data.data[0:1]==a5

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 Filtering Out DIFOP Port Number.

Appendix H Clean of LiDAR

H.1 Attention

Before cleaning the RS-LiDAR, please read through this entire Appendix F. Otherwise, improper handling can permanently damage it.
When the sensor is used in a harsh environment, it is necessary to clean it in time to keep its performance.

H.2 Required Materials

(1) Clean microfiber cloths
(2) Mild, liquid dish-washing soap
(3) Spray bottle within warm, clean water
(4) Solution of Isopropyl alcohol
(5) Clean gloves

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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Smart Sensor, Safer World

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