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Revision History

Revision Number	Description	Date	Edited by
1.0	Initial release	2019-11-20	PD

Terminology

MSOP	Main data Stream Output Protocol
FOV	Field of View
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
Thermolysis	Loss of Heat from the Object

TABLE OF CONTENTS

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

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-Ruby, the 128-beam LiDAR developed by RoboSense, is the world leading Multi-Beam LiDAR that is particular utilized in and perception of environment for autonomous driving.

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

- Measurement rang 200 meters
- Vertical angle resolution up to 0.1°
- Accuracy ± 5 centimeter
- Data rate up to 2,304,000 points/second
- Horizontal field of view (FOV) of 360°
- Vertical field of view (FOV) of -25°~15°

128 emitters in RS-Ruby can supply high-frequency laser impulse to scan environment around LiDAR by rapidly spinning optical module. 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 perception.

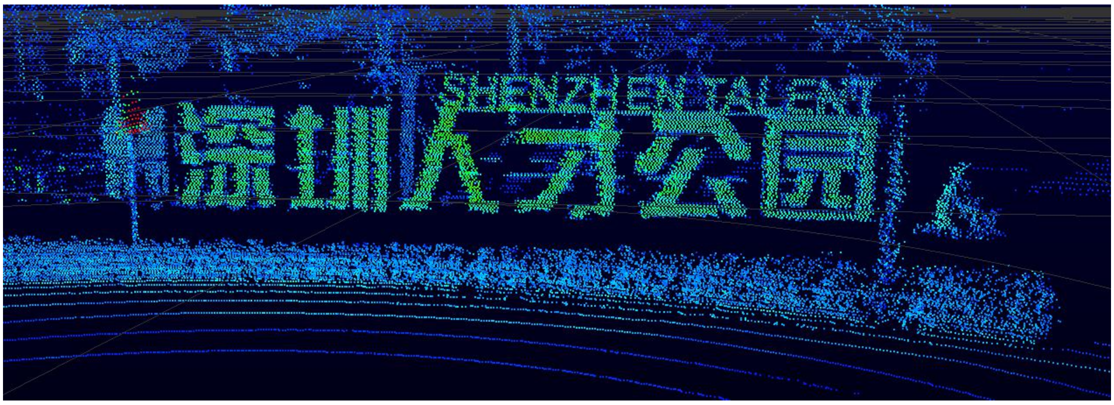


Figure 1. Representation of RS-Ruby Imaging.

The operating Instructions of LiDAR:

- Connecting the device of RS-Ruby;
- 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 ● 128 channels ● Range: from 3m to 230m (160m@10%)[2] ● Accuracy: upto ±3cm (typical value)[3] ● FOV(vertical): -25°~+15° ● Angle resolution(vertical): at least 0.1° ● 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 1.5 mrad, vertical 3.6 mrad
Output	● Data rate: ~2.3 million points/second ● 1000Base-T1 Ethernet ● Communication protocol: UDP ● The Information that is included in Data Segment: Distance Rotation angle/Azimuth Calibrated reflectivity Synchronized timestamp (Timer resolution 1 μs)
Mechanical/ Electrical/ Operational	● Power consumption: 45 W(typical)[4] ● Working voltage: 9-32 VDC (19V is recommended) ● Weight: 3.75kg (without cable) ● Dimensions: Diameter 166mm × Height 148.5mm ● Ingress Protection Rating: IP67 ● Operation temperature: -40℃~+60℃[5] ● Storage temperature: -40℃~+85℃

[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 160 m 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.

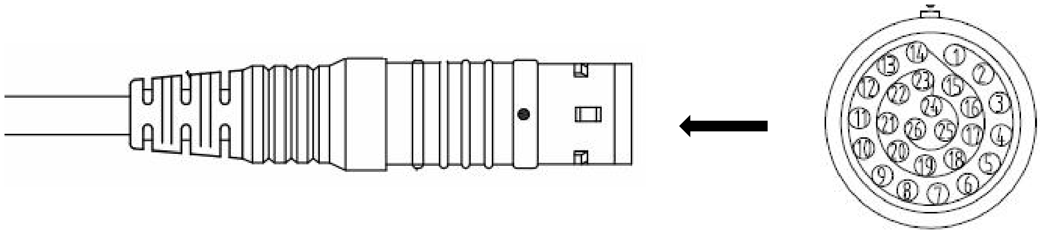
4 Interface

4.1 Power supply

The supply voltage should remain in the range of 9~32 VDC with utilization of Interface-Box. The recommend supply voltage is 19 VDC. The power consumption is about 45 W.

4.2 Data Output interface of LiDAR

The data output access of RS-Ruby 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:



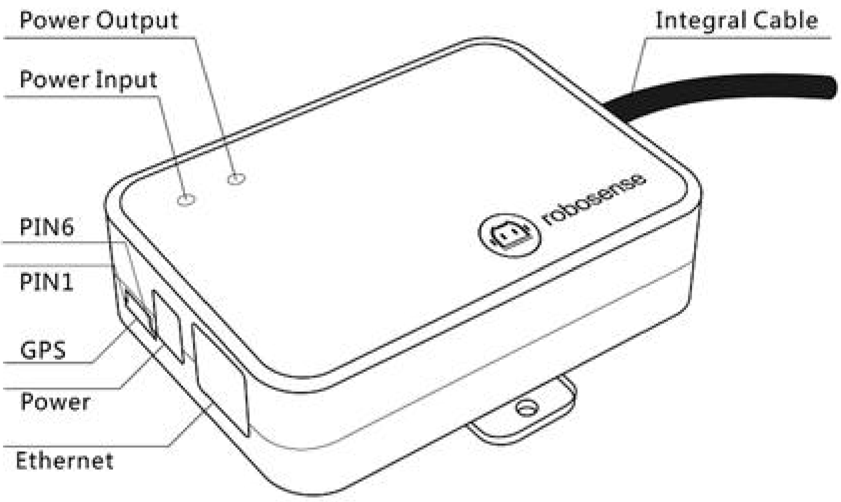
PIN	Wire Color	Function
1	Black/Brown	GROUND
2	Black	Gigabit network differential signal
3	Brown	Gigabit network differential signal
4	Black/Green	GROUND
5	Red	Gigabit network differential signal
6	Orange	Gigabit network differential signal
7	White/Orange	GROUND
8	Yellow	Gigabit network differential signal
9	Green	Gigabit network differential signal
10	White/Purple	GROUND
11	Blue	Gigabit network differential signal
12	Purple	Gigabit network differential signal
13	Yellow/Brown	GROUND
14	Black/Red	GROUND
15	Black/Orange	PWR
16	Black/Yellow	PWR
17	White/Black	PWR
18	White/Brown	PWR
19	White/Red	PWR
20	White/Yellow	PWR
21	White/Green	Reserved serial signal
22	White/Blue	Reserved serial signal
23	Yellow/Green	GPS_PULSE

24	Yellow/Gray	GPS_REC
25	Yellow/Blue	Reserved signal
26	Yellow/Purple	GROUND

Figure 2. Aviation Connector PIN Number

4.3 Interface Box

In order to connect the RS-Ruby 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-Ruby data transport.



PIN No.	function
1	GPS_PULSE
2	+5V
3	GND
4	GPS_REC
5	GND
6	NC

Figure 3. Interface Definition of Interface Box.

Note: When RS-Ruby 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

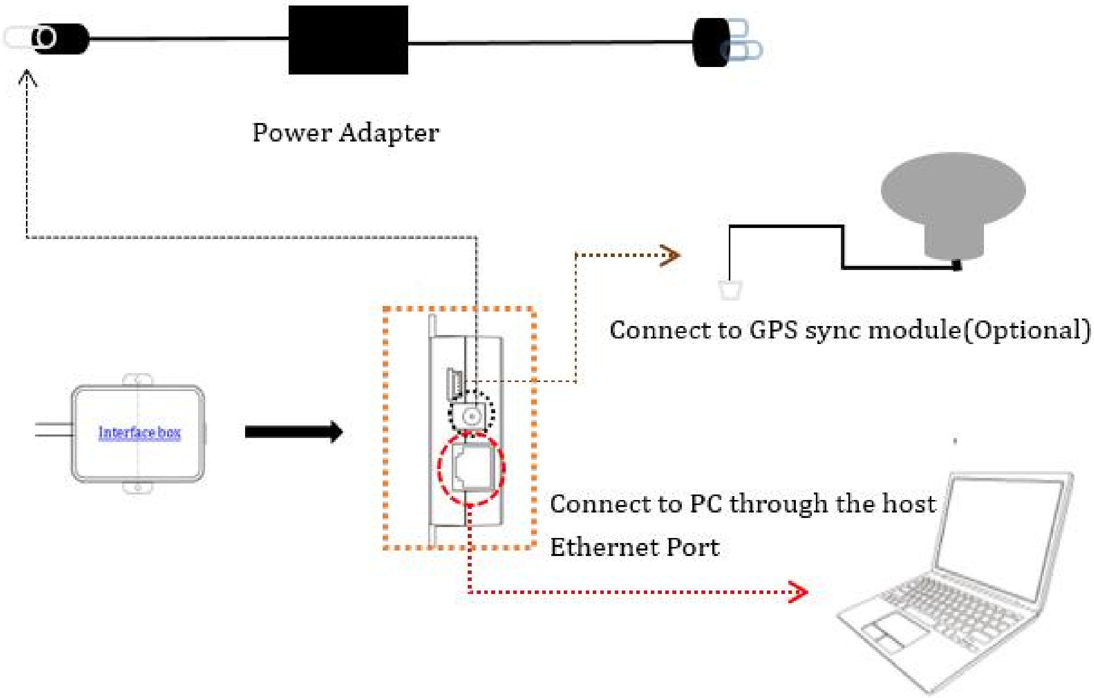


Figure 4. Diagram of Interface Box connection.

5 Communication Protocol

RS-Ruby adopts IP/UDP protocol and communicates with computer through gigabit Ethernet. In this User Guide the length of UDP packet is set up to 1248 byte. The IP address and port number of RS-Ruby is set in the factory as shown in the Table 2, but can be changed by user as needed.

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

	IP Address	MSOP Port No.
RS-Ruby	192.168.1.200	6699
PC	192.168.1.102	

The default MAC Address of each RS-Ruby is already set up in the factory with uniqueness. In order to establishing the communication between a RS-Ruby 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.

The output message from RS-Ruby is called MSOP. The Information of MSOP is shown as follow：

Table 3. Overview of the MSOP.

Protocol	Abbreviation	Function	Type	Size	Interval
Main data Stream Output Protocol	MSOP	Scan Data Output	UDP	1248 byte	~167 μs

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

5.1 MSOP

I/O type: Device outputs data and computer parses data.

Default port number is 6699.

MSOP packet outputs data information of the 3D environment. Each MSOP packet from sensor is 1248-byte length and consists of reported distance, calibrated Reflectivity values, azimuth values and a timestamp in UDP header.

Each MSOP packet payload is 1248-byte length and consists of an 80-byte header and a 1164-byte data field containing 3 blocks of 388-byte data records and a last 4-byte tail.

The basic data structure of a MSOP packet for single return is as shown in Figure 5:

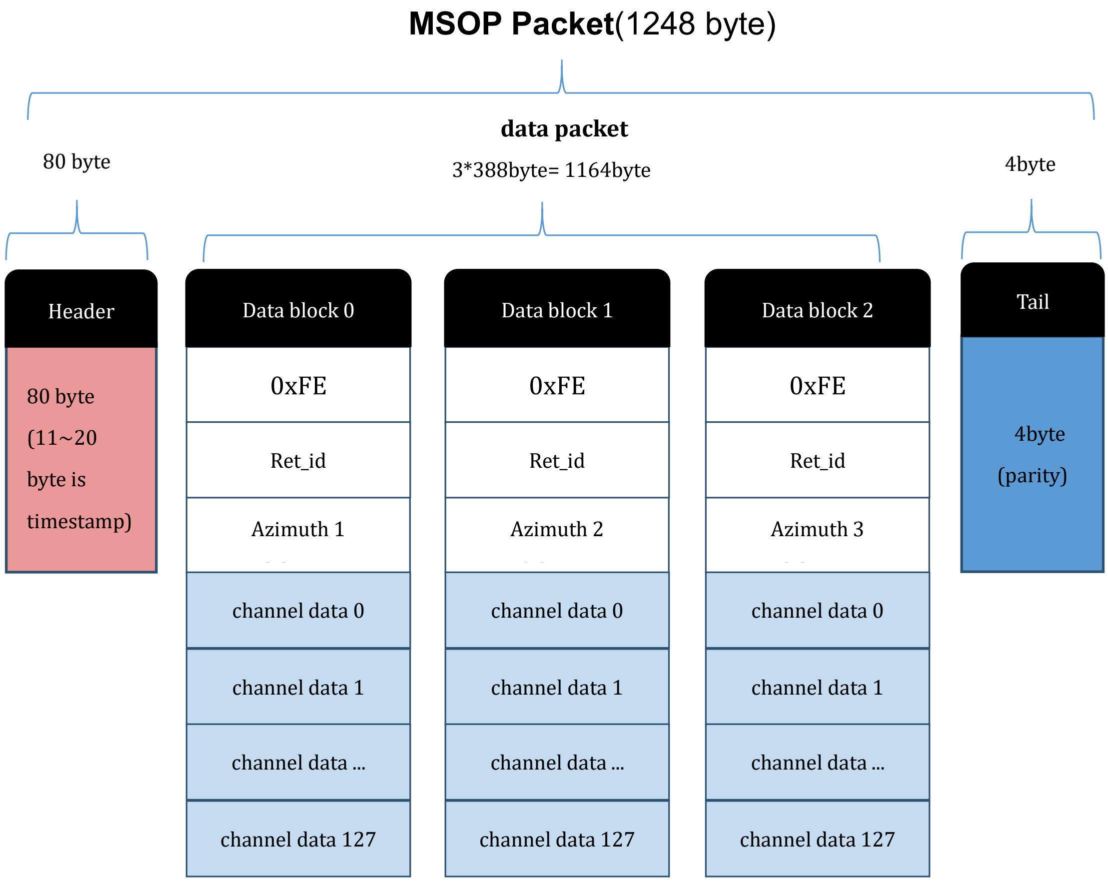


Figure 5. MSOP Packet of RS-Ruby in Single Return Mode.

5.1.1 Header

The 80-byte Header is used to mark the start position of data, return mode setting, sensor temperature and timestamp. The detail of the header is as shown in Table 4.

Table 4. Format of Header.

Header(80bytes)					
Header	Resv	Wave_Mode	Temp	Time	Resv
4bytes	3bytes	1bytes	2bytes	10bytes	60bytes

header: this can be used for packets identification: 0x55, 0xAA, 0x05, 0x5A (Default Value)

wave_mode: Big-Endian mode, lower 4 bit is used to representing the return mode of the LiDAR, for instance:

00000011 stands for that first and second return mode is chosen.

00000001 stands for that first return mode is chosen.

00000010 stands for that second return mode is chosen.

temp: the temperature of device;

time: it is used to save the timestamp. In the defined timestamp the system time is recorded, resolution 1us, the definition of time can be found in the appendix A.9 and the table 8 of this chapter.

resv: those bytes are reserved.

5.1.2 Data Field

The value of measurement result is saved in the data field, in total 1164 byte. It consists of 3 data blocks, the length of each data block is 388 bytes. Each block stands for a complete round of distance measuring for all 128 channel. The definition is shown as follow:

Table 5. Data Block Definition

Data block n(388bytes)					
Symbol	Ret_id	Azimuth	Channel0_data	...	Channel127_data
1bytes	1bytes	2bytes	3byte	...	3bytes

Symbol: identification bit, default value: 0xfe;
Ret_id: it is used to represent which echo measurement is for this block;
Azimuth: the information of horizontal rotation angle. This angle information will be used to calculate the 3D coordinate with all following 128 channel data in the same block. In following section, it will be completely explained.
Channel data: the length of each channel data is 3 bytes, each block includes 128 channel data (further details could be seen in Table 6). (The relationship between the number of channel and vertical angle can be found in chapter 8.)

5.1.2.1 Calculation of the Azimuth

In each data block the value of azimuth is measured once and this azimuth corresponds to the first position of the first laser emission (the first channel data in this block). The rotation angle is recorded by angle encoder. The zero position of angle encoder is the zero degree of azimuth. The resolution of resolution angle is 0.01°.
For instance, in figure 6, the azimuth value is calculated as follow:

Get azimuth values (HEX): 0x59, 0x39
Combine to a 16bit, unsigned integer (HEX): 0x 5939
Convert the value to decimal (DEC): 22841
Division by 100 (DEC): 228.41°

Hence, the angle value in this block is 228.41°.

Note: the 0°axis of azimuth is co-axis and same positive direction with the Y axis in Figure 8.

5.1.2.2 Channel Data

Channel data is 3 bytes. The higher 2 bytes of them are used to save the distance information. The lower one byte stands for reflectivity.

Table 6. The Format of Channel Data.

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

Distance is 2 bytes, resolution: 0.5 cm.

For instance, in figure 6, the explanation of Channel data is as follow:

Get the higher 2 bytes(HEX): 0x08 (Distance 1), 0x4b (Distance 2).

Combine to a 16-bit unsigned integer (HEX):0x084b

Convert the value to decimal (DEC):2123

*According to the resolution 0.5 cm, change to meter: 2123 * 0.005 = 10.615 m*

Hence, the distance between sensor and measurement object is 10.615 m.

Reflectivity is a relative value, please find the concrete definition in "chapter 9 Reflectivity", Reflectivity could show energy of the light return from measuring object in the real circumstance. Through analytic of reflectivity, the object of different materials can be distinguished.

5.1.3 Tail

The 4-byte Tail is reserved to identification.

5.1.4 MSOP Data Package

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

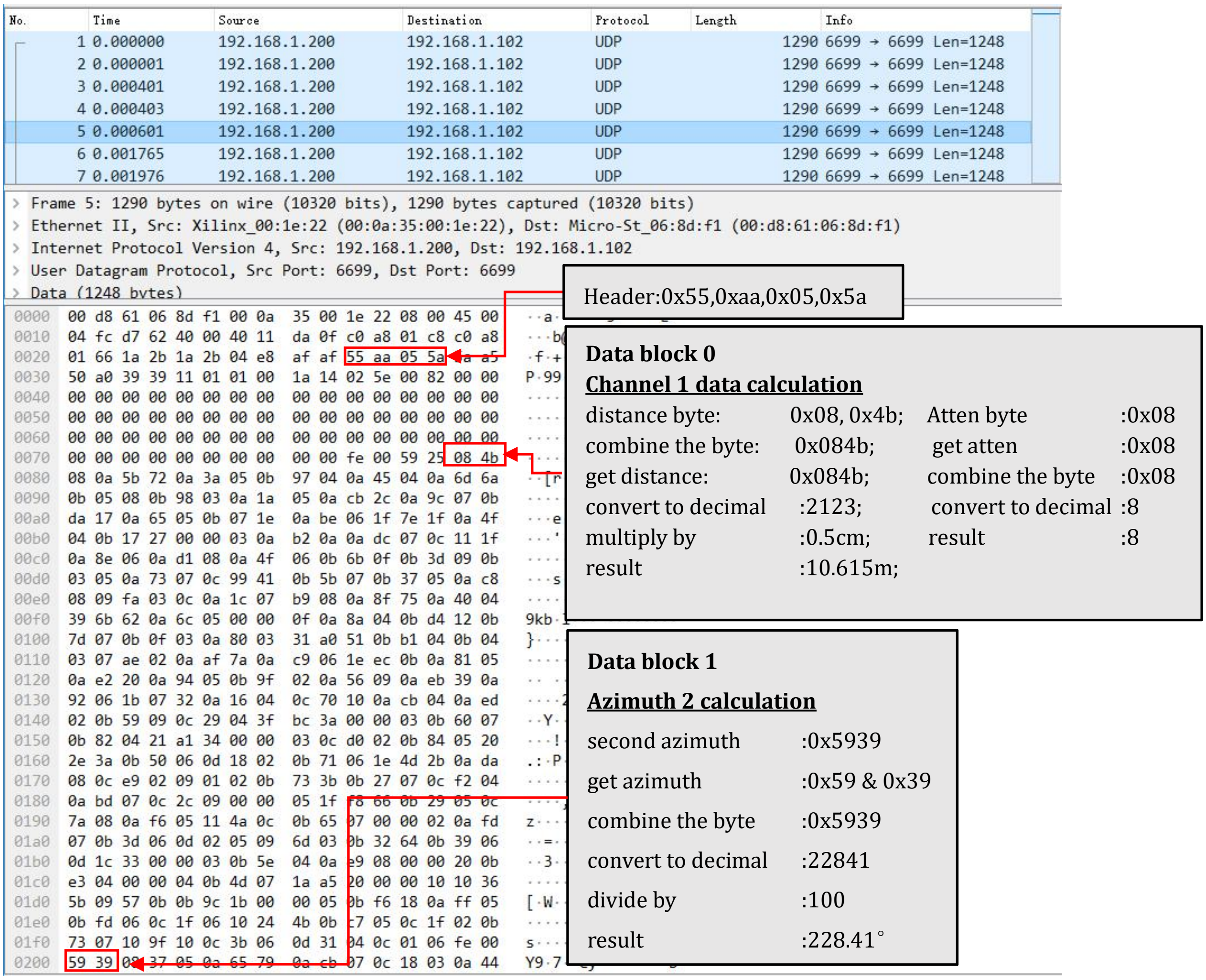


Figure 6. MSOP Packet of RS-Ruby in Single Return Mode.

6 GPS Synchronization

RS-Ruby supports external GPS receiver connections. With GPS connections, we can synchronize the RS-Ruby system time to GPS global time.

6.1 Principle of GPS synchronization

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

GPS_REC receives the signal from GPS module with Standard serial RS232 communication protocol.
GPS PULSE receives the PPS from the GPS module and requests voltage between 3.0 V ~ 15.0 V.
PIN +5V of GPS interface can supply power to GPS module. (If GPS module is only allowed to use +3V as power supply, please don't use this +5V PIN on Interface Box. Please exchange the +5V to +3V)
PIN GND is connected to the GPS receives ground wire.
The GPS module should set to 9600bps baud rate, 8-bit data bit, no parity and 1 stop bit.
RS-LiDAR-Ruby 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
The different GPS module could send out different GPRMC message length, the RS-Ruby could be compatible with the most GPS modules on the market. Please contact RoboSense of technical support when it is incompatible.

7 Key Specifications

7.1 Return Mode

There are two return modes on RS-Ruby: strongest return and last return mode. Because of laser divergence, after any laser emission the sensor can receive always more than one return signals. If return mode is set up to the strongest return mode, only the strongest return signal can be seen as useful signal in distance calculating. Similarly, if the setting is the last return mode, only the last return signal can be used to calculate distance.

7.2 Phase Lock

The Phase Lock feature can be used to make the sensor rotating to the specific position when the PPS signal is triggered. To operate correctly, the PPS signal must be present and locked stable.
In figure 7 different Phase Lock is shown as red arrow. When PPS is triggered, sensor can rotate to the 0°, 135°or 270°.

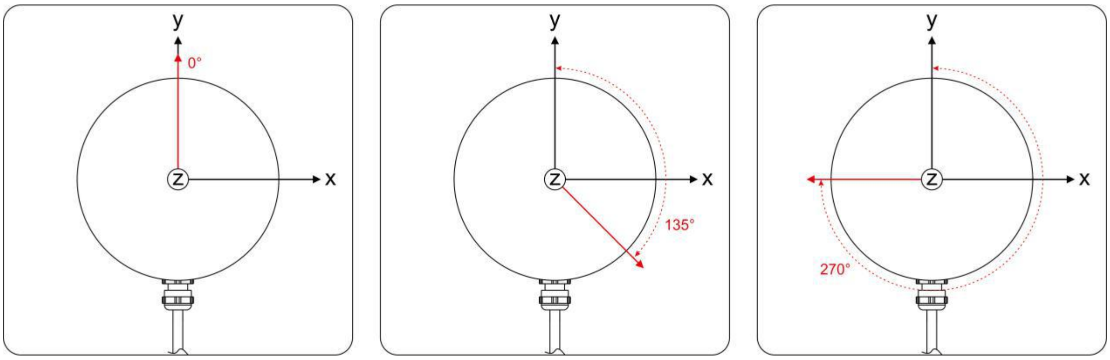


Figure 7. Different phase lock angles 0°/135°/270°.

In RSVIEW Client **"Tools > RS-LiDAR Information",** a parameter "Phase Lock" can be set up. Here, Phase can be set in the input range of 0°~ 359°.

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 8. 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/elevation 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 value of ω and δ defined in Table 7.

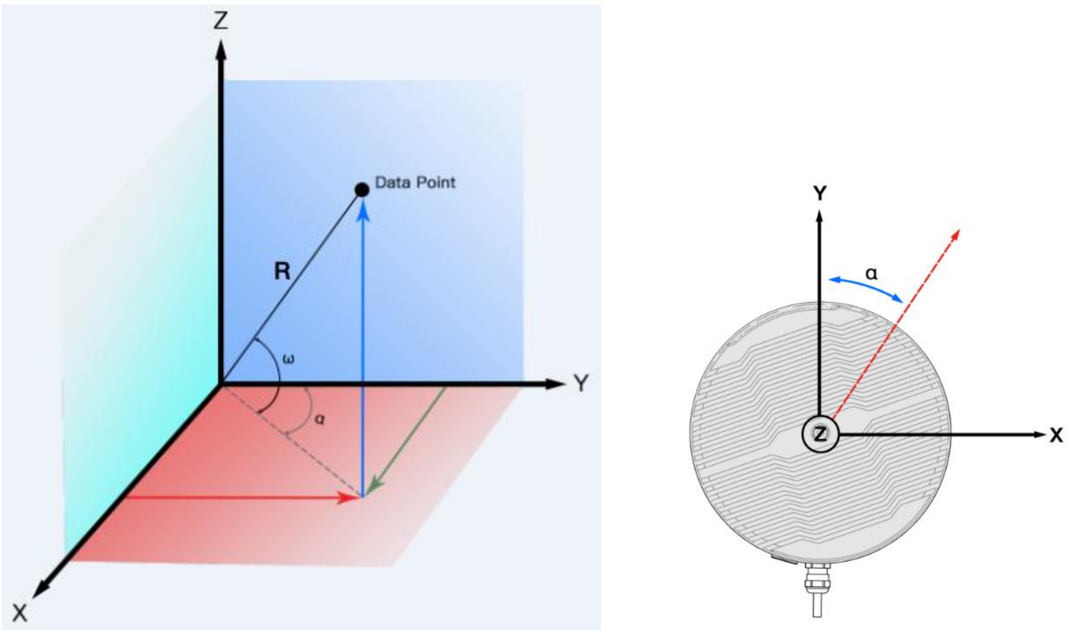


Figure 8. Coordinate system mapping between polar system and XYZ system.

Note 1: In the RS-Ruby 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 8.

The ROS-Y axis is co-axis with the X-axis but the positive direction is reverse as Figure 8.

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 68 mm high to the bottom of the LiDAR.

8.2 Laser Channel in spatial Distribution

128 lasers in RS-Ruby are defined as 128 channels. The vertical angle of those lasers distribute in the range of -25°~+15°. The distribution of the angles is non-uniform. According to table 7 the corresponding channel and vertical angle are as follow.

Table 7. Serial number of laser channel and corresponding horizontal angles.

Channel No.	Vertical Angle	Horizontal Offset Angle
1	-13.565	5.95
2	-1.09	4.25
3	-4.39	2.55
4	1.91	0.85
5	-6.65	5.95
6	-0.29	4.25
7	-3.59	2.55
8	2.71	0.85
9	-5.79	5.95
10	0.51	4.25
11	-2.79	2.55
12	3.51	0.85
13	-4.99	5.95
14	1.31	4.25
15	-1.99	2.55
16	5.06	0.85
17	-4.19	5.95
18	2.11	4.25
19	-19.582	2.55
20	-1.29	0.85
21	-3.39	5.95
22	2.91	4.25
23	-7.15	2.55
24	-0.49	0.85
25	-2.59	5.95
26	3.71	4.25
27	-5.99	2.55
28	0.31	0.85
29	-1.79	5.95
30	5.96	4.25
31	-5.19	2.55
32	1.11	0.85

33	-0.99	5.95
34	-4.29	4.25
35	2.01	2.55
36	-25	0.85
37	-0.19	5.95
38	-3.49	4.25
39	2.81	2.55
40	-7.65	0.85
41	0.61	5.95
42	-2.69	4.25
43	3.61	2.55
44	-6.09	0.85
45	1.41	5.95
46	-1.89	4.25
47	5.46	2.55
48	-5.29	0.85
49	2.21	5.95
50	-16.042	4.25
51	-1.19	2.55
52	-4.49	0.85
53	3.01	5.95
54	-6.85	4.25
55	-0.39	2.55
56	-3.69	0.85
57	3.81	5.95
58	-5.89	4.25
59	0.41	2.55
60	-2.89	0.85
61	6.56	5.95
62	-5.09	4.25
63	1.21	2.55
64	-2.09	0.85
65	-8.352	-0.85
66	-0.69	-2.55
67	-3.99	-4.25
68	2.31	-5.95
69	-6.19	-0.85
70	0.11	-2.55
71	-3.19	-4.25

72	3.11	-5.95
73	-5.39	-0.85
74	0.91	-2.55
75	-2.39	-4.25
76	3.96	-5.95
77	-4.59	-0.85
78	1.71	-2.55
79	-1.59	-4.25
80	7.41	-5.95
81	-3.79	-0.85
82	2.51	-2.55
83	-10.346	-4.25
84	-0.89	-5.95
85	-2.99	-0.85
86	3.31	-2.55
87	-6.39	-4.25
88	-0.09	-5.95
89	-2.19	-0.85
90	4.41	-2.55
91	-5.59	-4.25
92	0.71	-5.95
93	-1.39	-0.85
94	11.5	-2.55
95	-4.79	-4.25
96	1.51	-5.95
97	-0.59	-0.85
98	-3.89	-2.55
99	2.41	-4.25
100	-11.742	-5.95
101	0.21	-0.85
102	-3.09	-2.55
103	3.21	-4.25
104	-6.5	-5.95
105	1.01	-0.85
106	-2.29	-2.55
107	4.16	-4.25
108	-5.69	-5.95
109	1.81	-0.85
110	-1.49	-2.55

111	9	-4.25
112	-4.89	-5.95
113	2.61	-0.85
114	-9.244	-2.55
115	-0.79	-4.25
116	-4.09	-5.95
117	3.41	-0.85
118	-6.29	-2.55
119	0.01	-4.25
120	-3.29	-5.95
121	4.71	-0.85
122	-5.49	-2.55
123	0.81	-4.25
124	-2.49	-5.95
125	15	-0.85
126	-4.69	-2.55
127	1.61	-4.25
128	-1.69	-5.95

9 Reflectivity

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

RS-Ruby 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.

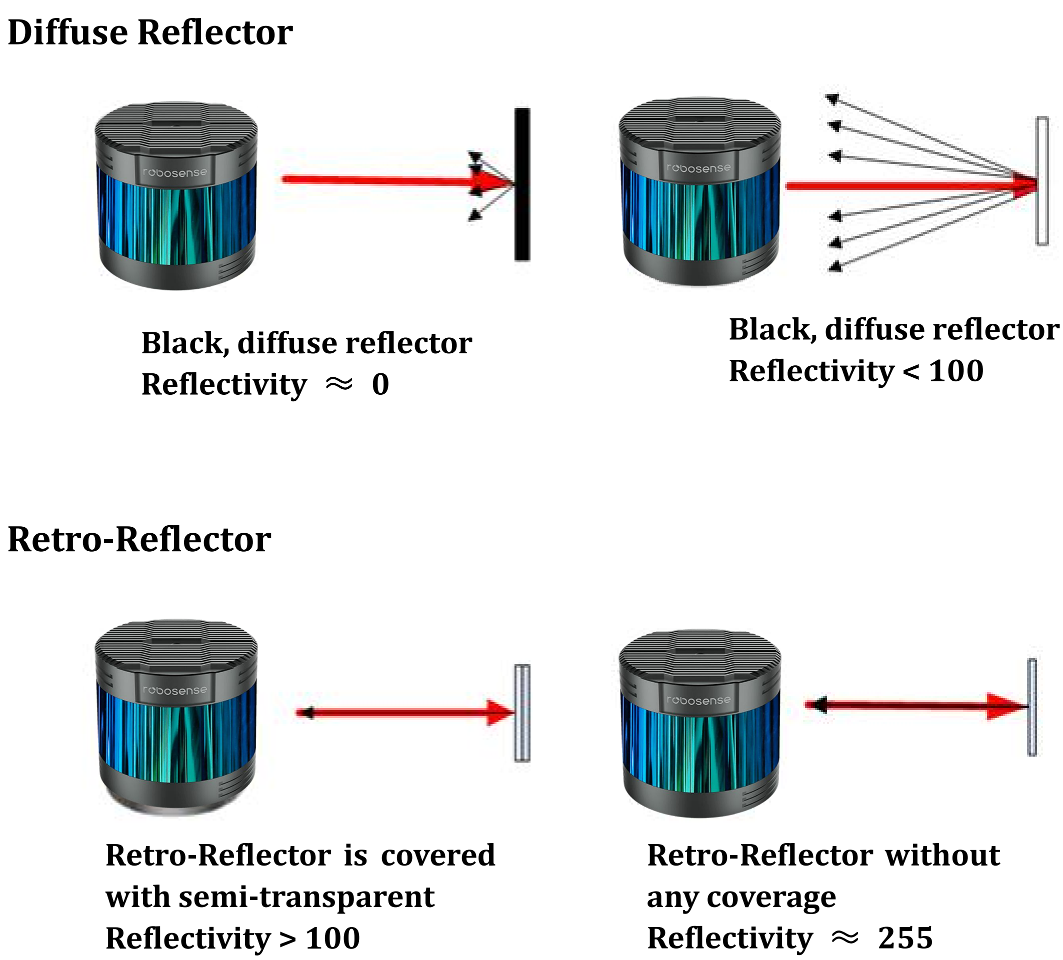


Figure 9. Calibration of reflectivity.

The value of reflectivity is already encapsulated in MSOP. It means that the reflectivity can be directly read.

10 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 4A @ 19V)
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 4A @ 19V) ● 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 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 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 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 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 – the Format of all Register

A.1 UTC_TIME

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

Explanation of each Byte in UTC：

1) year

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

reg name：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_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_μs[7:0]							

Note：set_μs[9:0]value：0~999

Appendix B RSView

In this appendix, the record, visualization, save and redisplay of the data from RS-Ruby 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-Ruby is used with RSView vision 3.1.5. or above.

B.1 Software Features

RSView can provide real-time visualization of 3D coordinate data from RS-Ruby. 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-Ruby. 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

B.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 executable installation packet can be found in USB stick with name "RSView_X.X.X_Setup.exe" from the RS-Ruby package. Also you can download the latest version from RoboSense website (http://www.robosense.ai/web/resource/en). Launch the installation packet and follow the instructions to complete the installation. The installation path should not contain any Chinese characters.

B.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.

B.4 Visualization of point cloud

1. Connect the RS-Ruby 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 B-1).

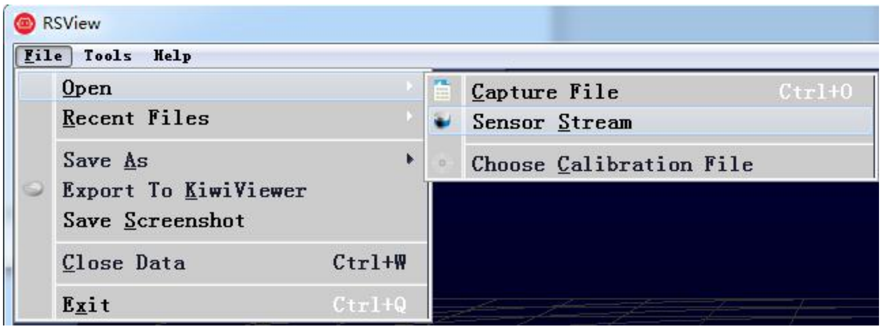


Figure B - 1. Open sensor stream in RSView.

4. After finishing above 3 steps, the dialogue box “Sensor Configuration” shows up. In this dialogue box, the default configuration folder of RS-Ruby calibration is already contained and the folder is already chosen. If there is chaos while display in RSView, please check and add the right configuration files folder. Click Add button then select corresponding file at last click OK (as shown in Fig B-2).

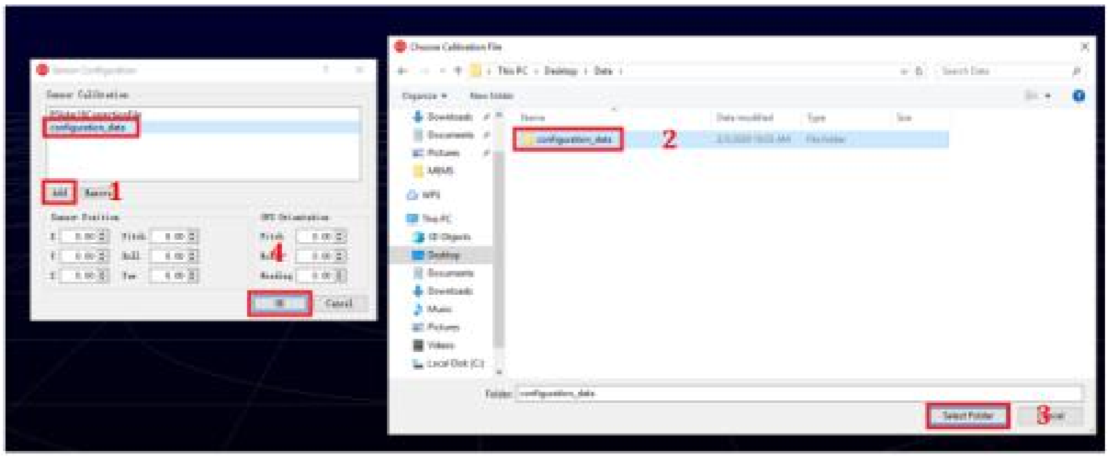


Figure B - 2. RSView Select Sensor Correction File.

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

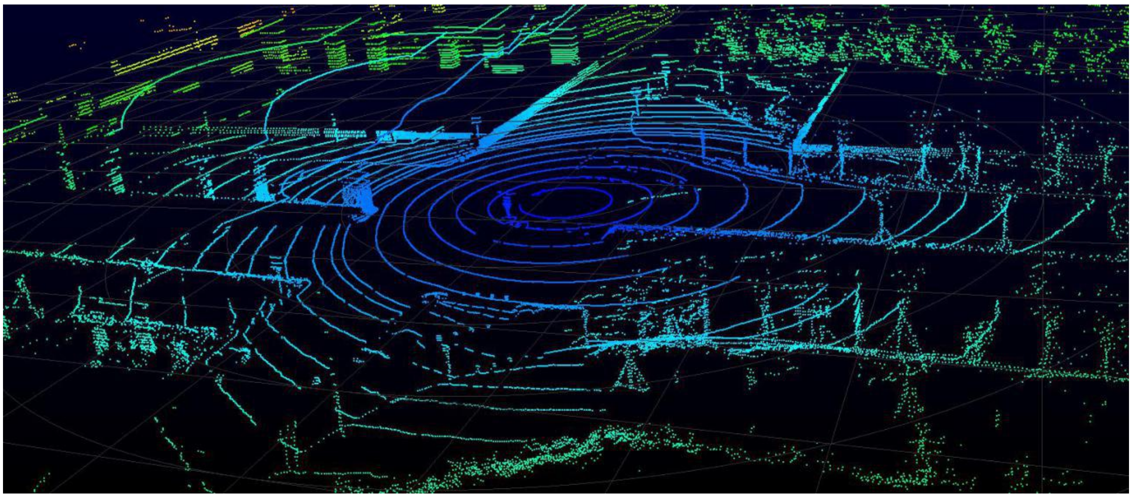


Figure B - 3. RSView Sensor Stream Display.

B.5 Save Streaming Sensor Data into PCAP File

1. Click the record button while real-time display (Fig. B-4).

Figure B - 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 B-5). After clicking "save" button, RSView begins writing data into pcap file. (Note: RS-Ruby 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.)

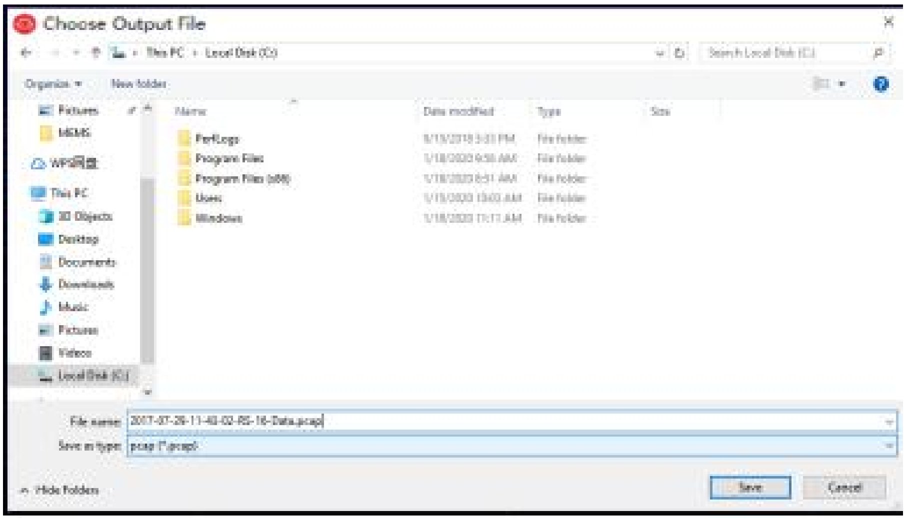


Figure B - 5. RSView Record Saving Dialog.

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

B.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.

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

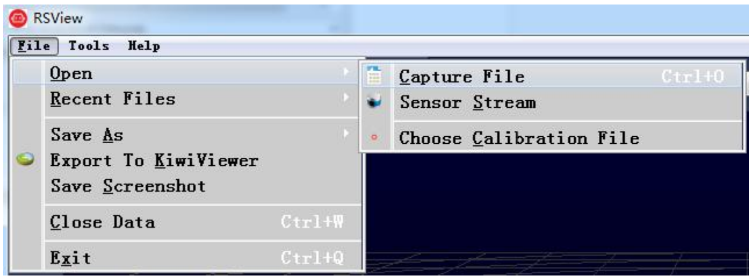


Figure B - 6. RSView Open Capture File.

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

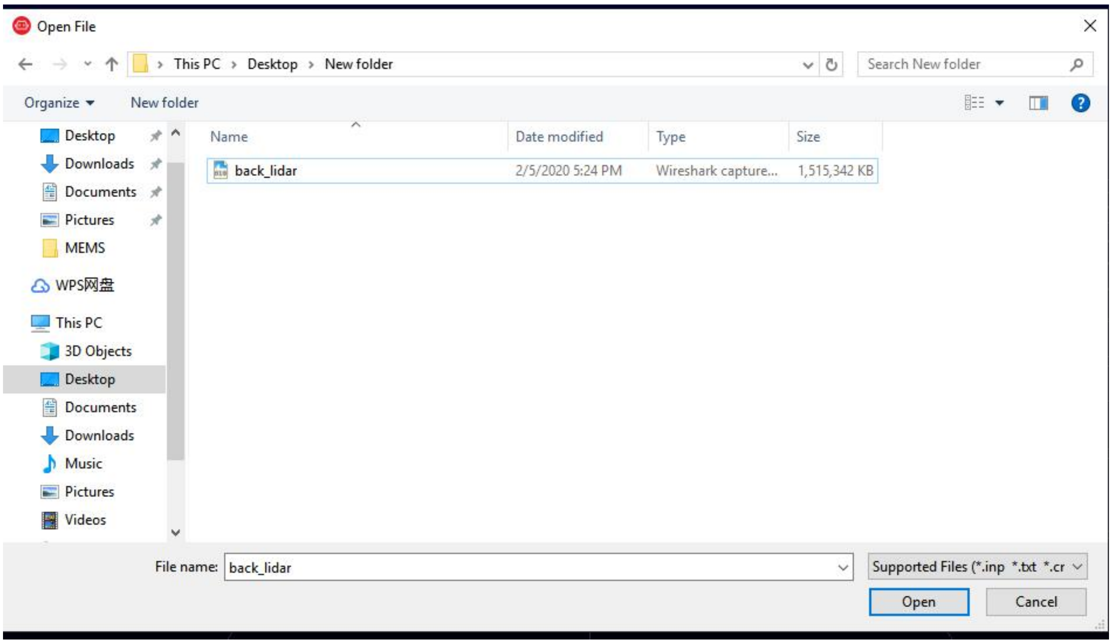


Figure B - 7. Select the PCAP File.

3. In dialogue box "Sensor Configuration", please add and select the right configuration file of RS-Ruby, 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. B-8)

Figure B - 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 B-9). A data table will

be displayed on the right side. It contains all displayed data points in the frame.

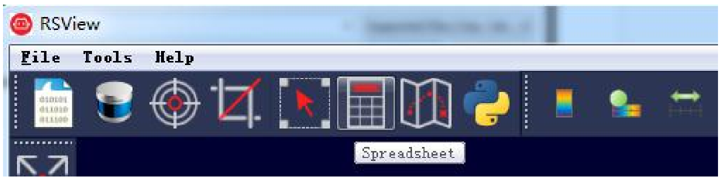


Figure B - 9. RSView Spreadsheet tool.

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

Showing: Data Attribute: Point Data Precision: 3 F

	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 B - 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. B-11)

Showing: Data Attribute: Point Data Precision: 3 F

	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 B - 11. RSView Show Only Selected Elements.

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

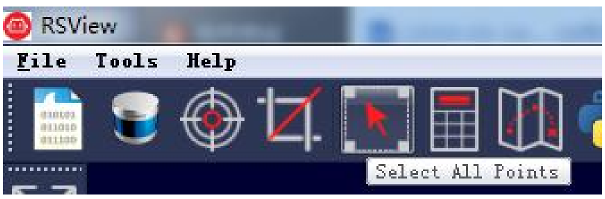
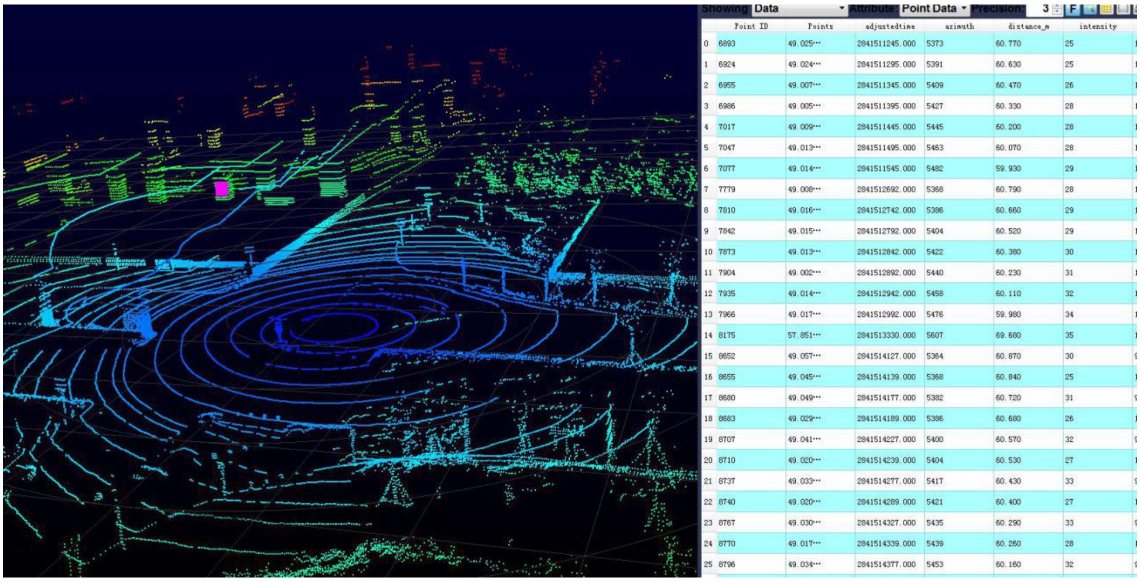


Figure B - 12. RSView Select All Points.

9. 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. B-13).



	Point ID	Points	adjustedtime	azimuth	distance_m	intensity
0	6893	49.025···	2841511245.000	5373	60.770	25
1	6924	49.024···	2841511295.000	5391	60.630	25
2	6955	49.007···	2841511345.000	5409	60.470	26
3	6986	49.005···	2841511395.000	5427	60.330	28
4	7017	49.009···	2841511445.000	5445	60.200	28
5	7047	49.013···	2841511495.000	5463	60.070	28
6	7077	49.014···	2841511545.000	5482	59.930	29
7	7779	49.008···	2841512692.000	5368	60.790	28
8	7810	49.016···	2841512742.000	5386	60.660	29
9	7842	49.015···	2841512792.000	5404	60.520	29
10	7873	49.013···	2841512842.000	5422	60.380	30
11	7904	49.002···	2841512892.000	5440	60.230	31
12	7935	49.014···	2841512942.000	5458	60.110	32
13	7966	49.017···	2841512992.000	5476	59.980	34
14	8175	57.851···	2841513330.000	5607	69.680	35
15	8652	49.057···	2841514127.000	5364	60.870	30
16	8655	49.045···	2841514139.000	5368	60.840	25
17	8680	49.049···	2841514177.000	5382	60.720	31
18	8683	49.029···	2841514189.000	5386	60.680	26
19	8707	49.041···	2841514227.000	5400	60.570	32
20	8710	49.020···	2841514239.000	5404	60.530	27
21	8737	49.033···	2841514277.000	5417	60.430	33
22	8740	49.020···	2841514289.000	5421	60.400	27
23	8767	49.030···	2841514327.000	5435	60.290	33
24	8770	49.017···	2841514339.000	5439	60.260	28
25	8796	49.034···	2841514377.000	5453	60.160	32

Figure B - 13. RSView Selected Points.

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

Appendix C RS-Ruby ROS Package

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

C.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.

C.2 Compile RS-Ruby 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 from USB stick:
The configuration_data is in the USB stick shipped with the LiDAR. Copy the launch file into specified folder. This path can be customized.
For example: rslidar_pointcloud/data/rs_ruby

C.3 Configure PC IP address

For the default RS-Ruby 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.

C.4 Display of the real-time data

1. Connect the RS-Ruby 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_ruby.launch
```

3. Open a new terminal:

```
rviz
```

Set the Fixed Frame to "rslidar", add a Pointcloud2 type and set the topic to "rslidar_points".

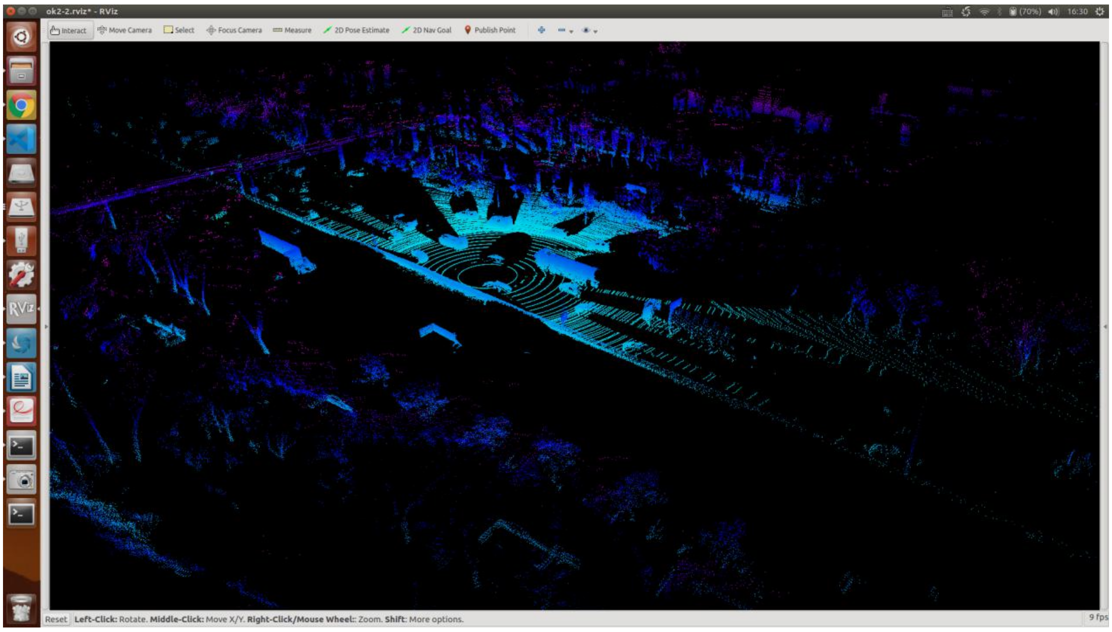


Figure C - 1. Display point cloud Data in rviz.

C.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_ruby.launch” file like below (please pay attention to the red code line):

```
<launch>
  <arg name="model" default="RS-ruby" />
  <arg name="device_ip" default="192.168.1.200" />
  <arg name="msop_port" default="6699" />
  <arg name="lidar_param_path" default="$(find rslidar_pointcloud)/data/rs_ruby/"/>
  <node   name="rslidar_node" pkg="rslidar_driver" type="rslidar_node" output="screen" >
    <param name="model" value="$(arg model)"/>
    <param name="device_ip" value="$(arg device_ip)" />
    <param name="msop_port" value="$(arg msop_port)" />
    <param name="pcap"   value="xxx.pcap absolute address"/>
  </node>
  <node   name="cloud_node" pkg="rslidar_pointcloud" type="cloud_node" output="screen" >
    <param name="model" value="$(arg model)"/>
    <param name="angle_path" value="$(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_ruby.launch
```

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

Appendix D Dimension

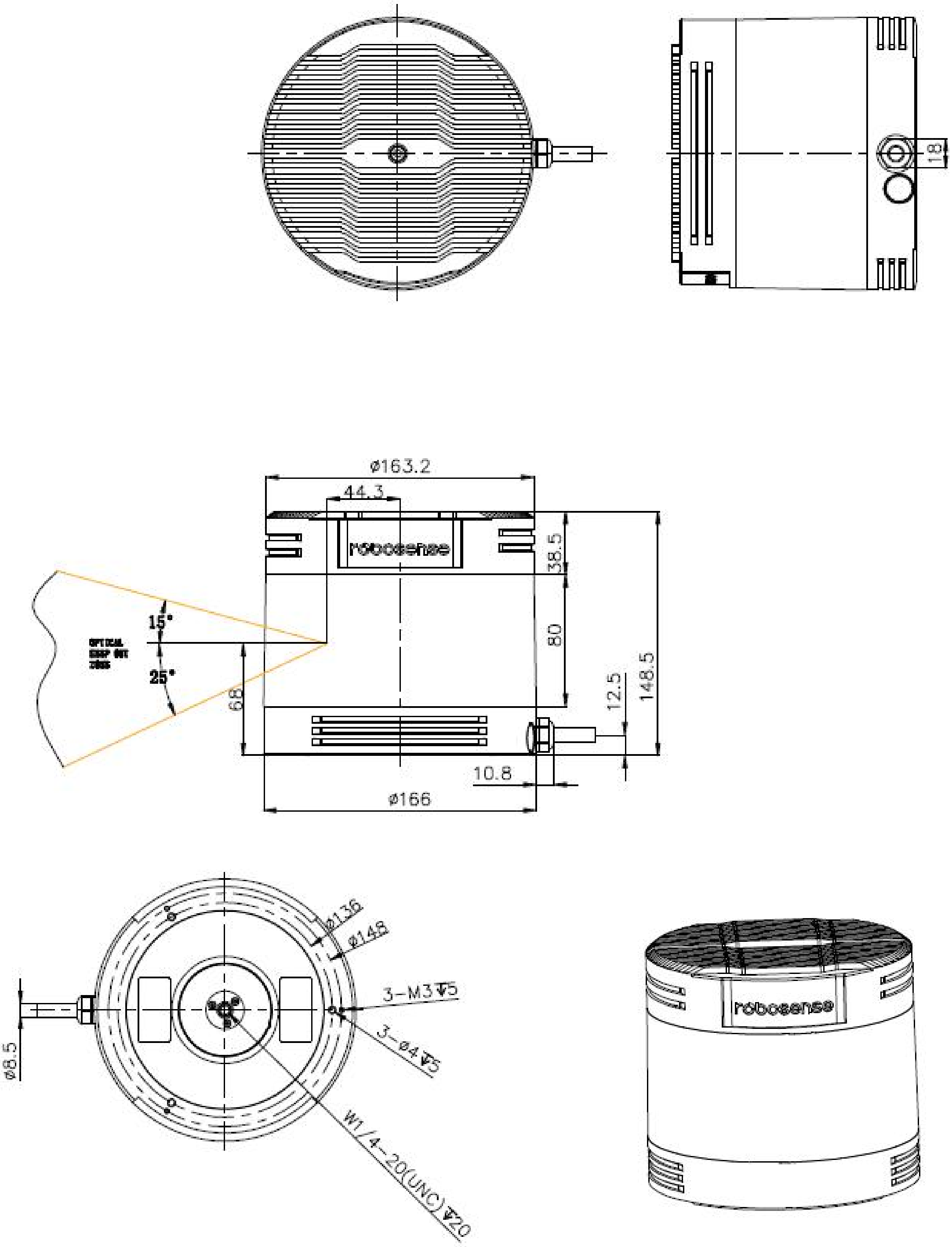


Figure D - 1: Dimension of Ruby.

Appendix E 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.
Please don't mount the LiDAR in a tilt position where the tilt angle exceeds 90 degrees, this will reduce the sensor life time.
When the LiDAR cable is routed in the mount device, please keep the cable a little slack, not too tense.

Appendix F Clean of LiDAR

F.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.

F.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

F.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.

400 6325 830

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