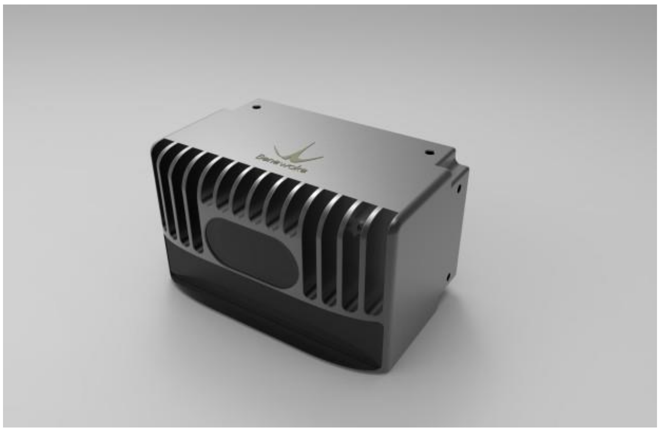
CE30-C Solid State Array LiDAR Specification



Benewake (Beijing) Co., Ltd

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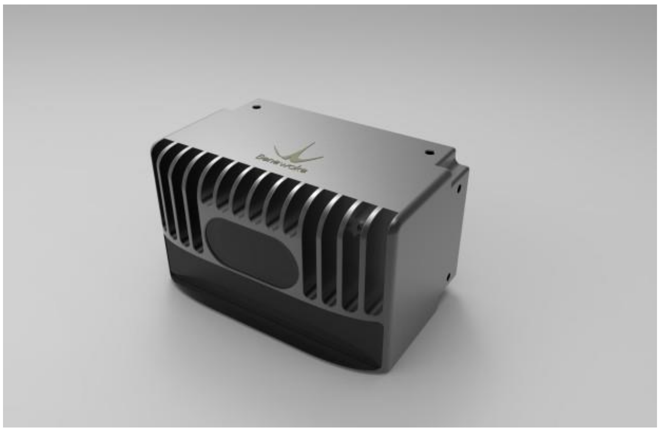
1. Product Overview



Feature

- Complete Solid-state LiDAR
- Area array detecting
- Wide horizontal FoV: >120°
- Vertical FoV: 9°
- Depth and point cloud mode

Table 1 CE30-C specification

Parameter[1]	**Typical Value**
Method	Time of flight
Peak Wave Length	850nm
FoV[2]	132*9 degrees
Pixel Resolution	320*24 (device output) 660*24 (SDK output with no loss of FoV[3])
Frame Rate	20fps
Response time	200ms
Ranging Resolution	1cm

[1] Specific parameters may slightly differ due to the test environment and the test method. 20 minutes warm-up time and white board with the reflectivity of 90% is used below as default. Please refer to section 4.3. Reflectivity of Various Materials.

[2] The FoV is open for customization.

[3] Please refer to section 11.2. Resolution and FoV of SDK Output.

Detection Range[4]	FoV's center: 0.1-4m FoV's edge: 0.1-2m
Accuracy[5]	≤6cm
Repeatability (1σ)[6]	≤4cm
Error Distribution	≤3cm: ≥53% ≤5cm: ≥85% ≤8cm: ≥97% ≤10cm: ≥98%
Ambient Light Suppression [7]	60klux
Data Interface	TCP
Operating Temperature	0-50℃
Storage Temperature	-30~70℃
Supply Voltage	DC 12V±1V (≥2A)
Power Consumption	≤6W
Dimensions	79*47*50mm
Enclosure Rating	IP65
Eye Safety Class	EN 62471 Exempt
Weight	219g

2. Principle of Ranging

The ranging principle of CE30 is based on Time of Flight (TOF). The modulated near-infrared light is emitted from CE30, which will be reflected by an object and received by CE30 again. CE30 calculates the phase difference and time difference between the emitted and received light, which will be converted to the clearance of the shot scene.

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[4] Different reflectivity and different angles correspond to different detecting ranges. Please refer to section 4. Detection Range Description. Typical value corresponds to the situation that detect directly white board with the reflectivity of 90%.

[5] Refers to the mean error of a 24*24 pixels area and the real distance. Typical value corresponds to the situation that directly detect white board with the reflectivity of 90%.

[6] Refers to the standard deviation of the output values when directly detect white board with the reflectivity of 90%.

[7] In case of usage under strong ambient light, the accuracy may slightly increase. Please refer to section 6. Outdoor Uses.

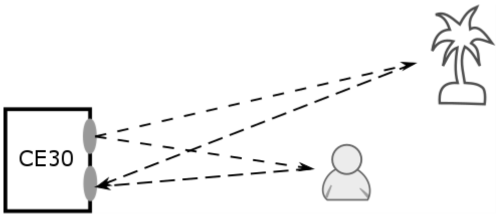


Figure 1 Schematic of CE30-C detecting range

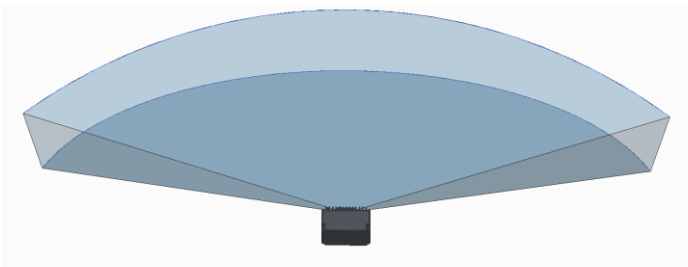


Figure 2 Illustration of CE30-C detection zone. Compared with single-line LiDAR, CE30 has a wider vertical FoV and therefore the obstacles can be better recognized.

3. Output Performance

By default, CE30-C outputs a depth image and corresponding intensity data for each pixel in each measurement. Figure 3 shows the actual scene captured by normal grey-scale camera (upper), the same scene captured by CE30-C and showed through depth image (middle), and the point cloud based on CE30-C's depth image (bottom, from the observation direct that a little higher than the CE30-C's position).

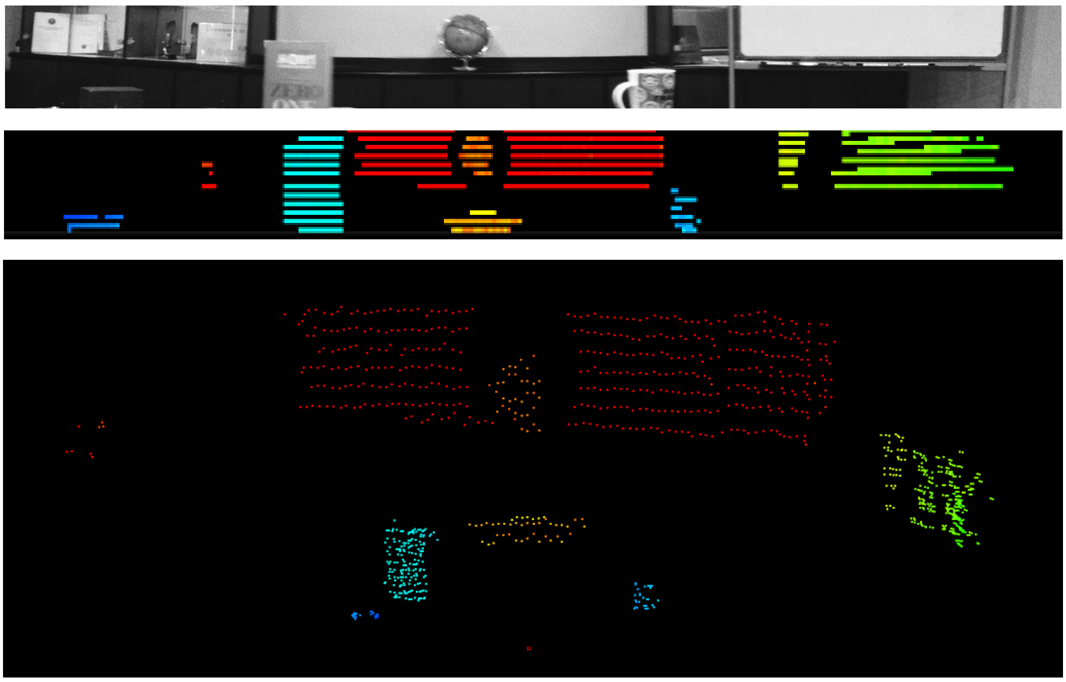


Figure 3 Comparison of real situation (upper, captured by a grey camera), CE30-C's depth image (middle) and CE30-C's cloud points (bottom)

Pixels receive the reflected infrared light within a field When the field contains infrared light reflected by far and near objects at the same time, the output distance data will have greater error. Thus CE30-C's embedded program will remove this part of data and set the corresponding pixel output to zero, forming the depth map in Figure 3. This processing causes the phenomenon that some object edges have no data, and leads to irregularities on the edges of detected objects. Depth data measurement also use high dynamic range (HDR) technology to expand the measurement range. In the CE30-C, the exposure time of each adjacent two pixel rows is set to different period. One is long and another is short: pixels with longer exposure time can reliably measure distant objects, and overexposure happens when it measure short-range objects; pixels with shorter exposure time can reliably detect objects in close range but will be underexposure when it measure distant objects. Therefore, when measuring an object at a certain distance, generally only one row of pixels in each adjacent two pixel rows has normal data output, forming the black stripe patterns of the depth image shown in Figure 3.

4. Detection Range Description

4.1. Blind Zone

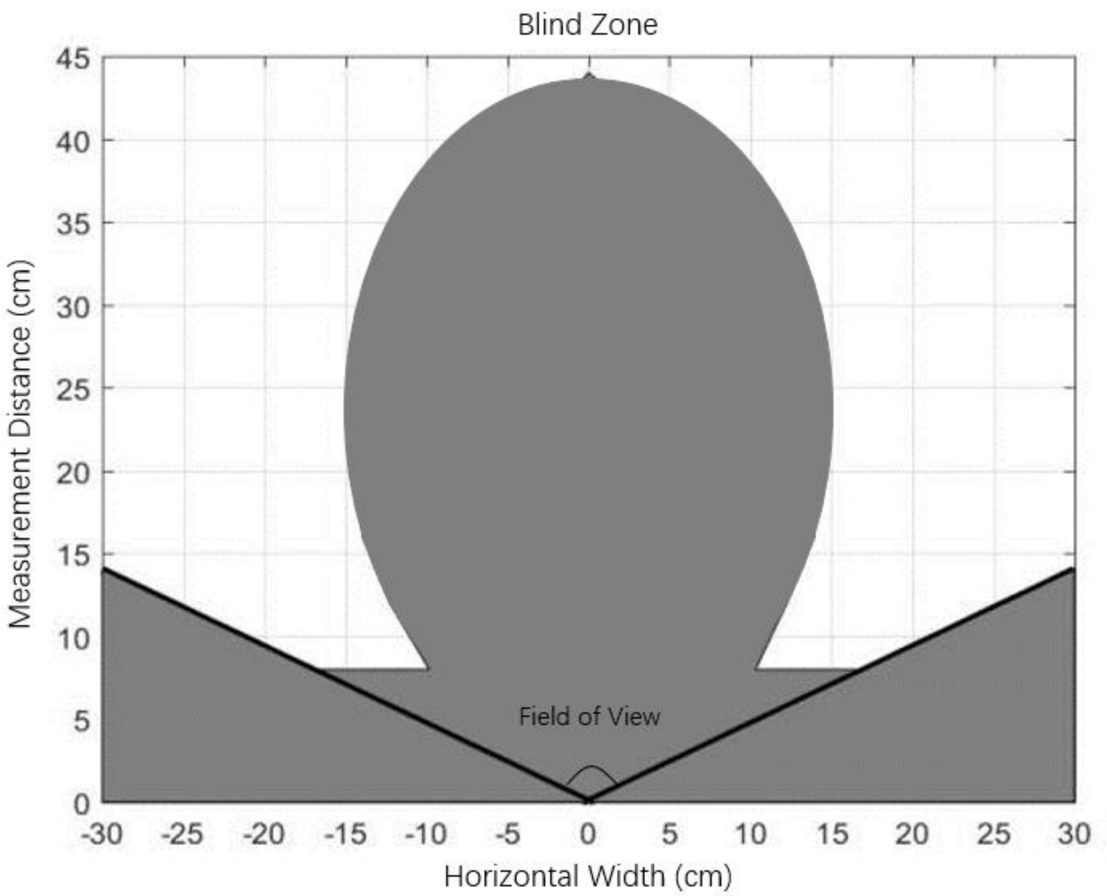


Figure 4 Blind zone distribution (test with 90% reflectivity objects)

When detecting objects with high reflectivity, except for the CE30-C's inherent blind zone of 0-10 cm, a blind zone as shown in Figure 4 would appear. This is caused by the overexposure when objects' reflected light is excessive. When the detected object's reflectivity is lower, the blind zone can become smaller.

4.2. Detection range

The maximum detectable range is different in different area of field of view. The detectable area of a 90% reflectivity object is shown in Figure 5.

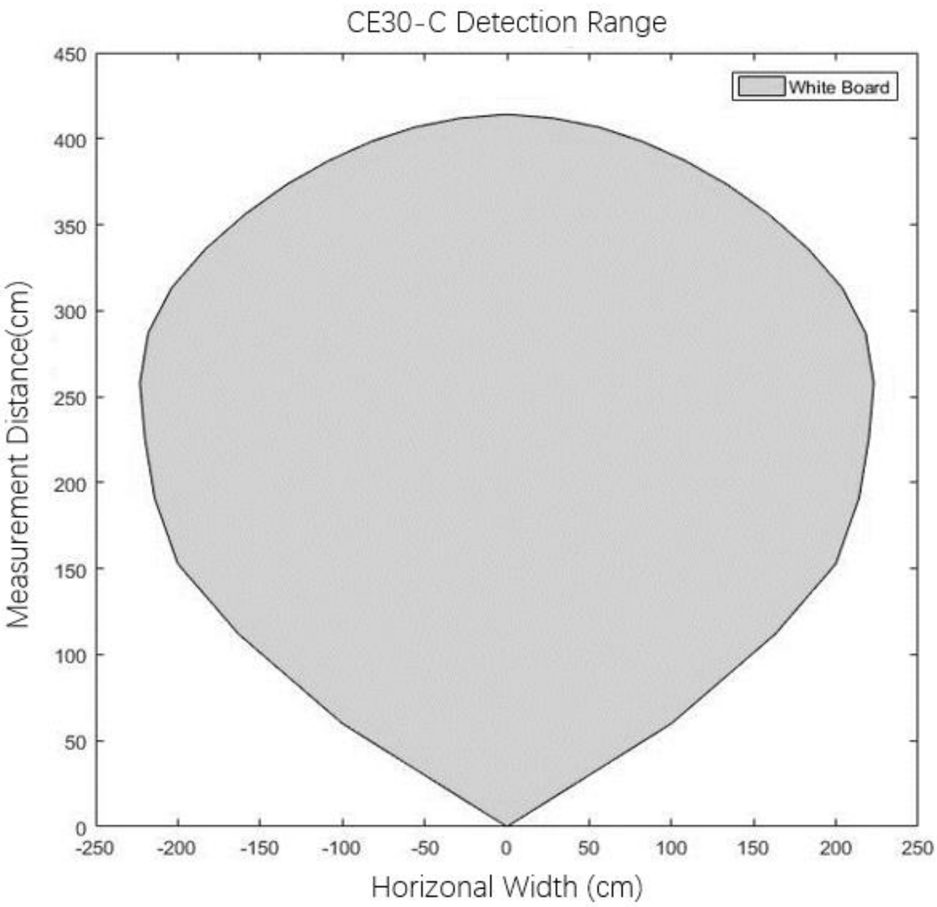


Figure 5 Detectable area in front of CE30-C

4.3. Reflectivity of Various Materials

Table 2 Reflectivity of various materials

No.	Material	Reflectivity
1	Black foam rubber	2.4%
2	Black cloth	3%
3	Black rubber	4%
4	Coal (various type coal is different)	4~8%
5	Black car paint	5%
6	Black cardboard	10%
7	Opaque black plastic	14%
8	Clean rough wood	20%

9	Newspaper	55%
10	Translucent plastic bottles	62%
11	Cardboard	68%
12	Clean pine	70%
13	Opaque white plastic	87%
14	White cardboard, white wall	90%
15	Kodak standard whiteboard	100%
16	Unpolished white metal surface	130%
17	Polished white metal surface	150%
18	Stainless steel	200%
19	Reflective panels, reflective stickers	>300%

5. Accuracy Description

5.1. Definition

The accuracy is defined as the difference between the average value of a 24*24 pixels area in the center of the field of view and the true distance value when detect a white board, whose reflectivity is 90%, under no ambient light condition. The repeatability is defined as the standard deviation of the average value of a 24*24 pixels area in the center of the field of view when detect a white board, whose reflectivity is 90%, under no ambient light condition.

Please refer to the Operation Manual for test details

5.2. Center of the Field of View

50 frames of data are recorded when detect a white board of 90% reflectivity. The data of 24*24 pixels area in the center of the field of view is selected to calculate the accuracy and repeatability in the range of 35cm to 305cm. The results are shown in Figure 6 and Figure 7. The selected area within 35cm contains part of overexposed blind zone, so that the measurement error is larger.

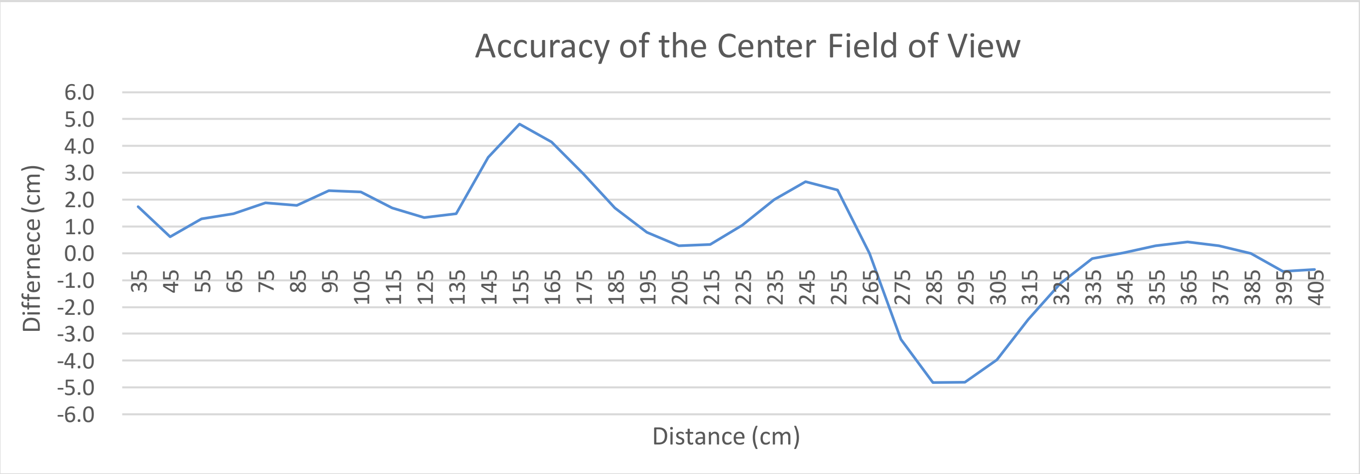


*Figure 6 Accuracy of the center 24*24 pixels area*

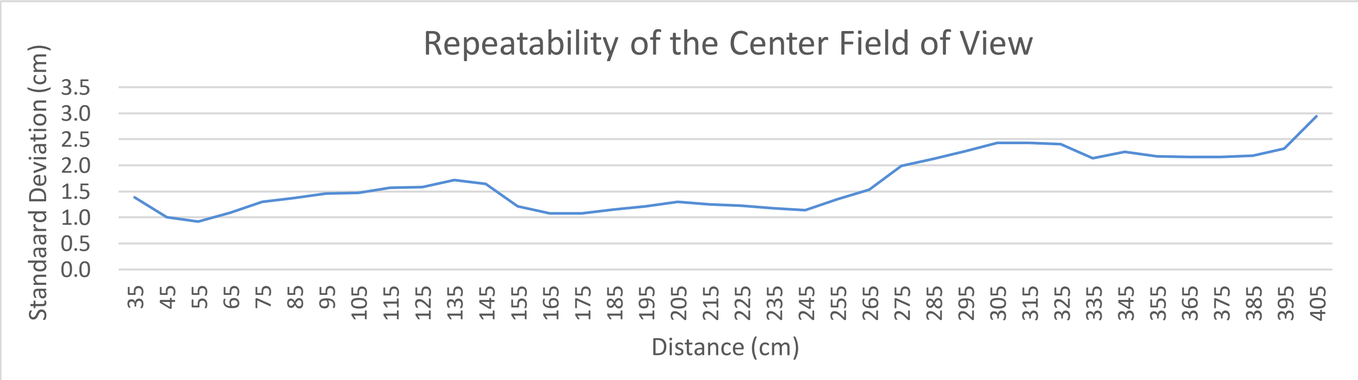


*Figure 7 Repeatability if the center 24*24 pixels area*

5.3. Edge of the Field of View

The edge area of the field of view is used to detect a white board of 90% reflectivity. 50 frames of data are recoded and are used to calculate the accuracy and repeatability of the edge area of the field of view. The results are shown in Figure 8 and Figure 9.

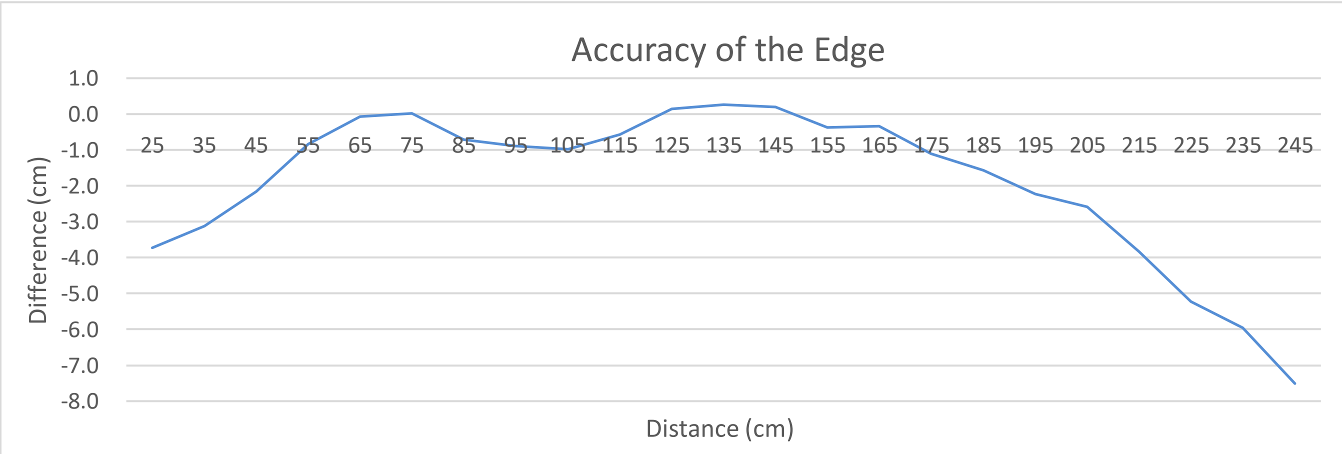


*Figure 8 Accuracy of the edge 24*24 pixels area*

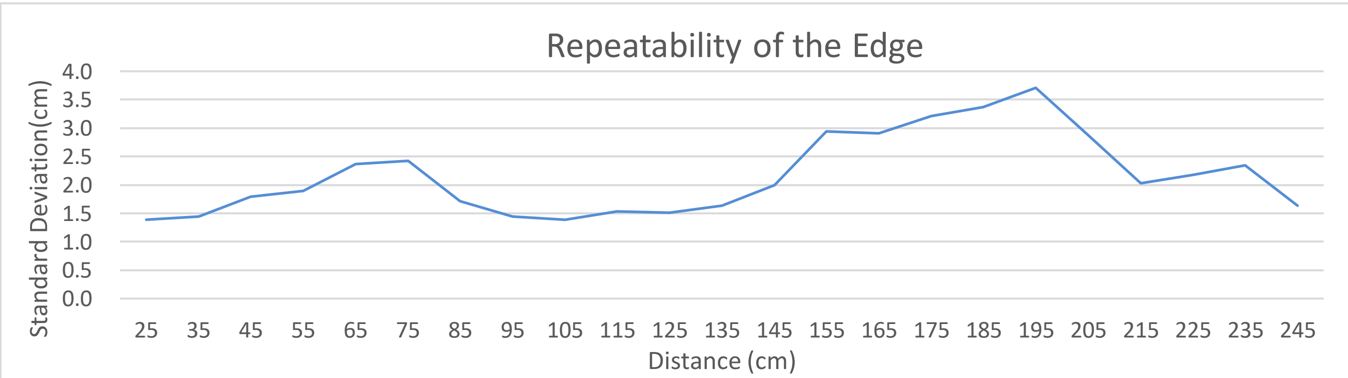


*Figure 9 Repeatability if the edge 24*24 pixels area*

5.4. Accuracy Spatial Distribution

To check the accuracy spatial distribution, 50 frames of data are recorded while using CE30-C to detect white wall (90% reflectivity) in the distance of 100cm. The error between the average value of each pixel column and the true distance is used to stand for accuracy, and the standard deviation of the average value of each pixel column between frames is used to stand for repeatability.

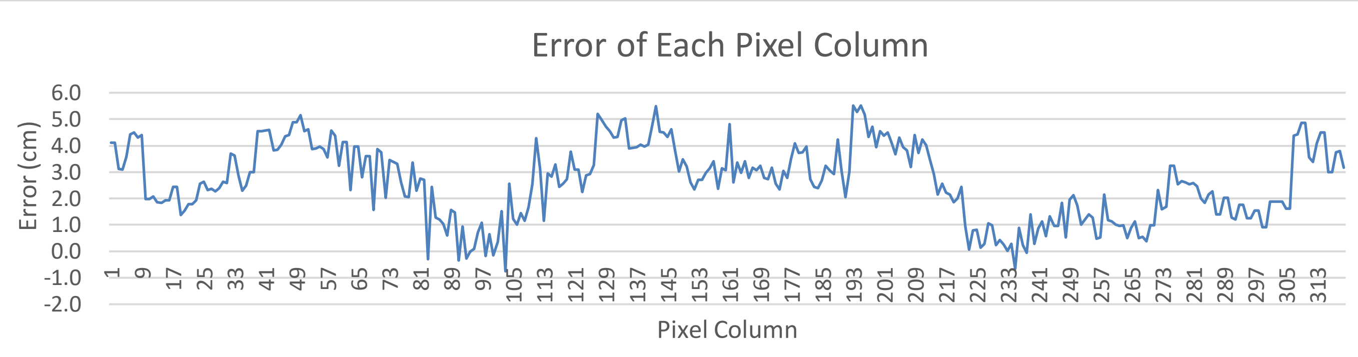


Figure 10 Accuracy spatial distribution when detect white wall in 100cm

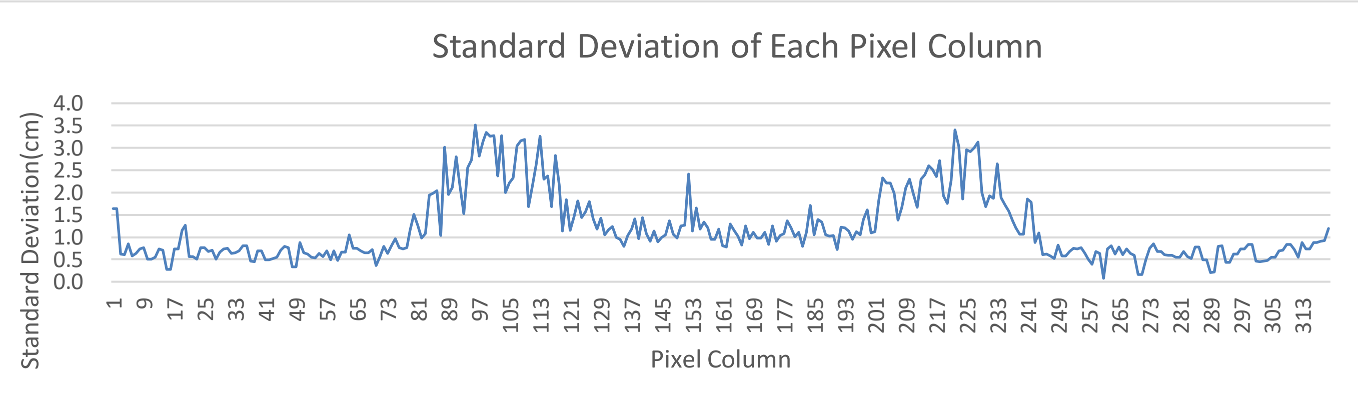


Figure 11 Repeatability spatial distribution when detect white wall in 100cm

6. Outdoor Uses

6.1. Test Conditions

When CE30-C is used in outdoor environment, due to the interference of ambient light, CE30-C's close blind zone, measurement error and standard deviation will increase. The test in this section is made under 30kLux ambient light. CE30-C is placed back to the sun and detect the white board that has 90% reflectivity and is illuminated by sunlight.

6.2. Outdoor Accuracy

Begin in the distance of 15cm, 50 frames of data are recorded per 10cm. Followings are the results of the recorded data.

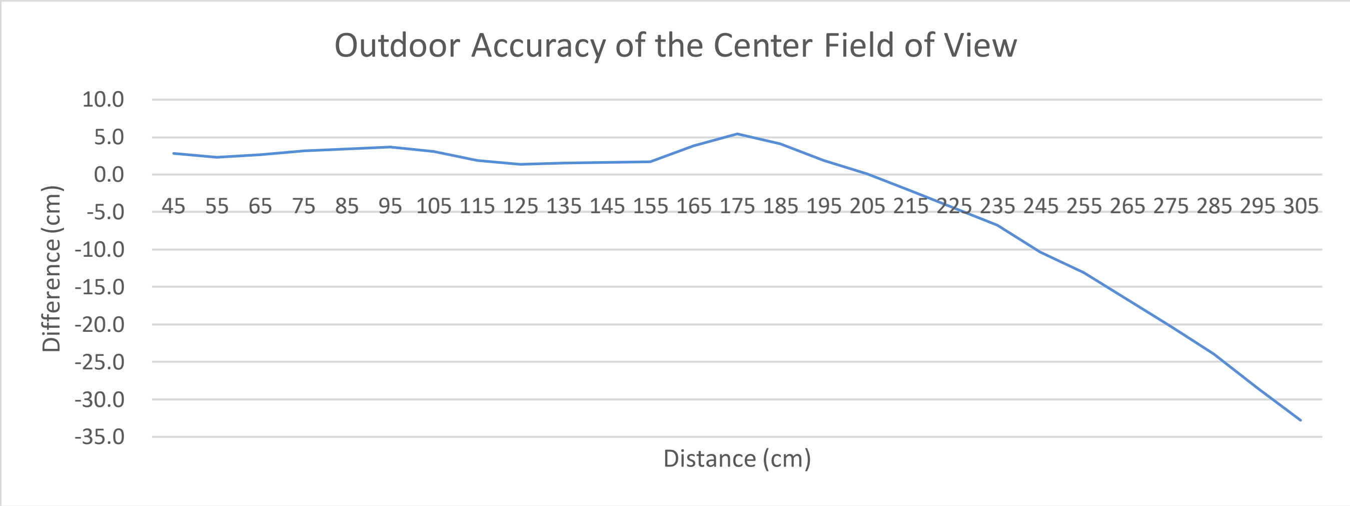


Figure 12 Outdoor accuracy of the center area of the field of view

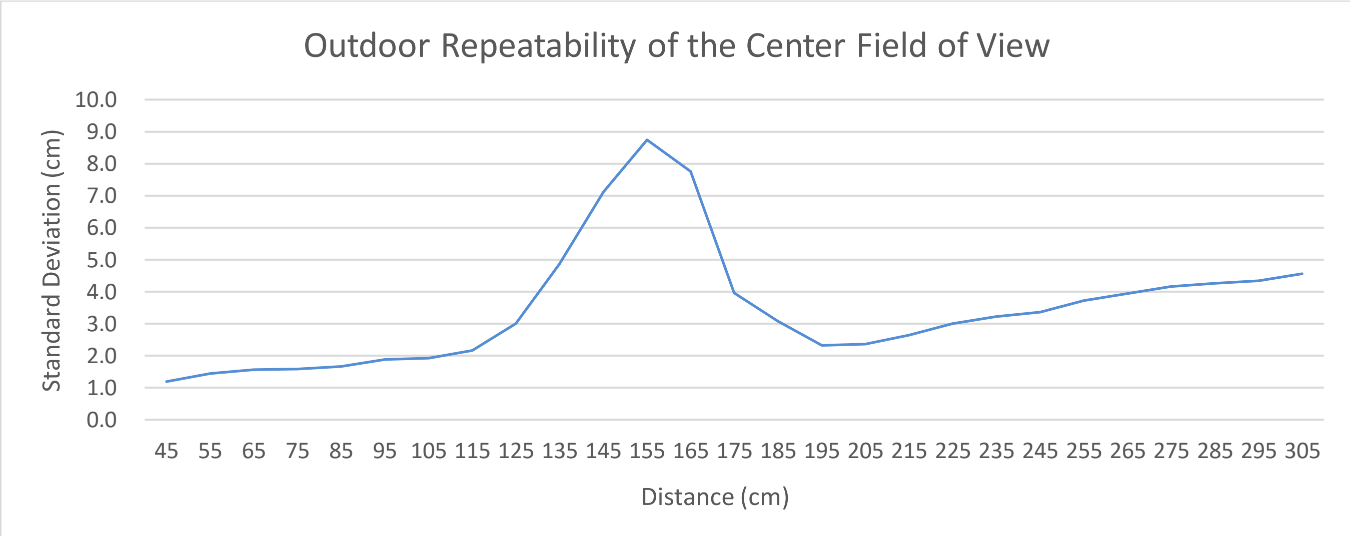


Figure 13 Outdoor repeatability of the center area of the field of view

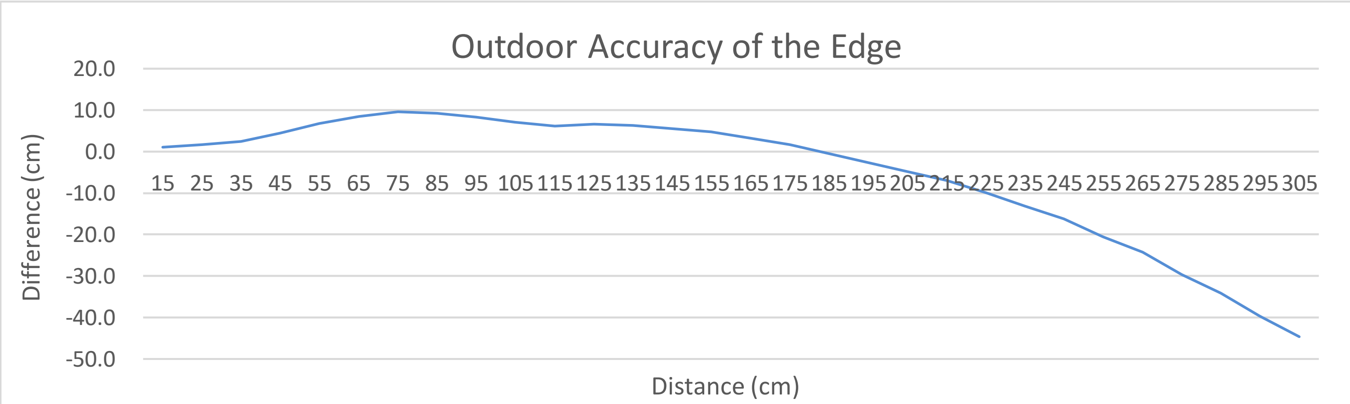


Figure 14 Outdoor accuracy of the edge of the field of view

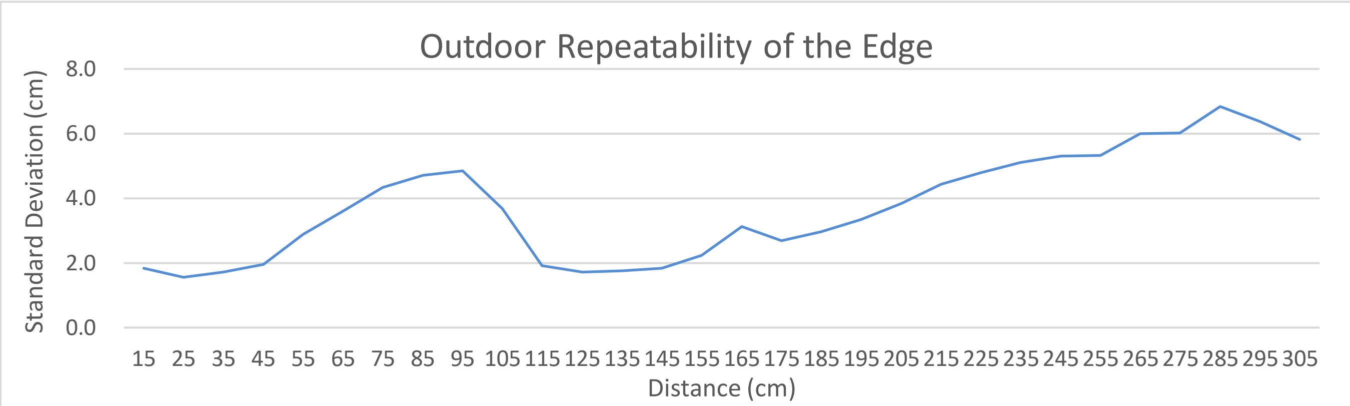


Figure 15 Outdoor repeatability of the edge of the field of view

7. Interference Between CE30-Cs

7.1. Interference When Face to Face

When two CE30-Cs detect face to face, interface happens because all CE30-Cs' detection light has the same wavelength. It causes the increase of detection error.

When two CE30-Cs interfere with each other at the distance of 2m, about 11.4% of the output frames will show an increase in detection error. The ratio increases as the two machines approach and decreases the two machines stay away from each other.

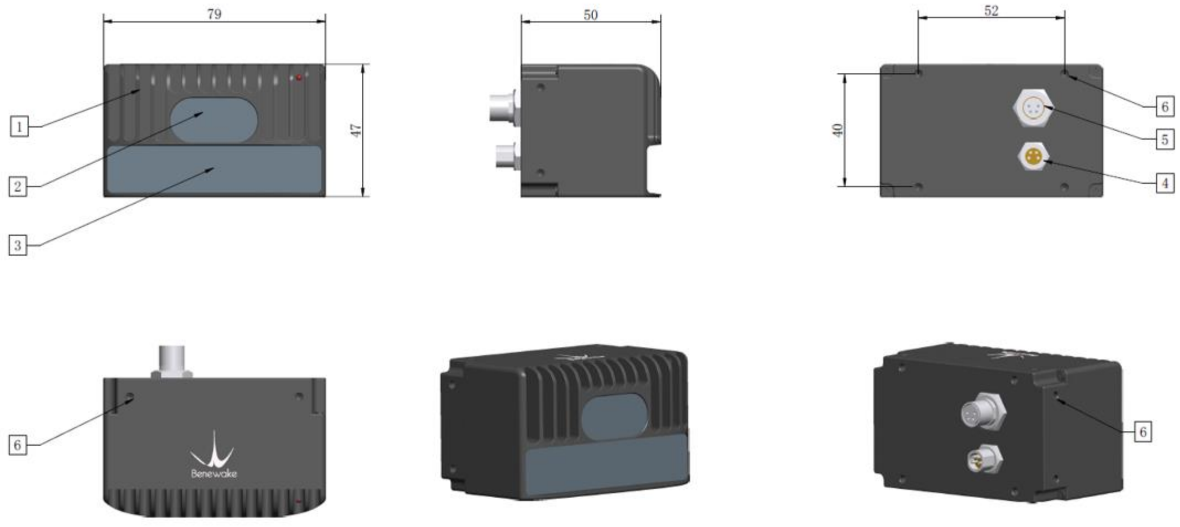
7.2. Interference When Parallel

Parallel interference refers to the situation that two CE30-Cs are parallelly placed to detect the same direction. The interference causes the detection error increases.

When two CE30-C are placed adjacent to each other at the same height, about 4.7% of the output frames will have an increased detection error. When two CE30-Cs are placed at an angle, the area where interference occurs in one frame will be reduced. When the included angle between two devices become larger, the interference will be smaller. When the center axes of the two CE30-Cs are larger than 110 °. the interfere disappears.

8. Product Dimensions

The following images of the modules and the outline dimensional drawings are the reference design. The customization based on customer demands and different application scenarios is available.



1. Shell
2. Reception panel (working area, cannot be covered)
3. Emitting panel (working area, cannot be covered)
4. Power/CANBUS port (M8 aerial socket)
5. Ethernet port (M8 aerial socket)
6. Equipment installation hole (M3)

Figure 16 CE30-C outline drawing

9. Aerial Socket Interface Description

Female: Ethernet connector, aerial socket with 8 mm diameter.

Male: Power supply/CANBUS connector, aerial socket with 8 mm diameter.

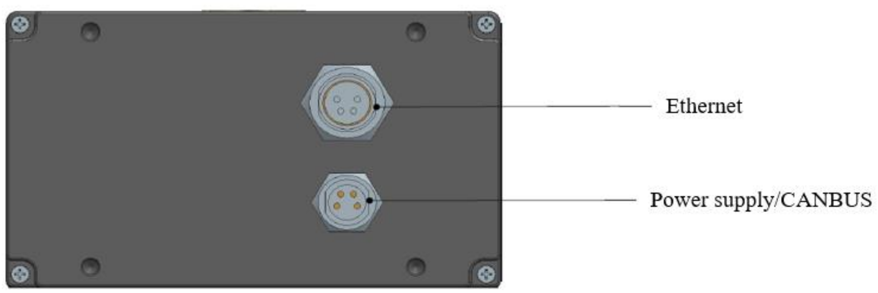
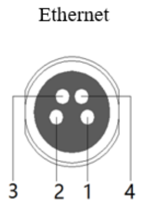


Figure 17 CE30-C aerial connection description

	Pin Number	Description
Power supply/CANBUS  1 4 3 2	1	CAN_L (unavailable)
	2	CAN_H (unavailable)
	3	GND-
	4	12V +

Figure 18 Power supply/CANBUS socket pin definition



Pin Number	Description
1	ETH_RX_P
2	ETH_RX_N
3	ETH_TX_P
4	ETH_TX_N

Figure 19 Ethernet socket pin definition

10. Output Interface

Ethernet interface is used in this LiDAR with standard TCP protocol. In the mainstream operating systems, no drive is demanded.

11. Software Description

11.1. SDK Description

The LiDAR initialization and start-up, data acquisition and LiDAR turn-off can be achieved through SDK. For the LiDAR application and development on the operating systems besides Linux, please refer to SDK source codes for transplantation and development.

Table 3 SDK description

Software	Description
Operating system	Linux & Windows
Programming language	C/C++
Data format	16-bit unsigned short int
Scope of the assignment	0 – 65535
Use method	Shared Object File (.so), Dynamic Link Library (.dll) or integrate SDK source codes into programs

11.2. Resolution and FoV of SDK Output

Due to the wide-angle short focal length optical system, the image obtained by CE30-C has barrel distortion. The algorithm in the SDK will calibrate the distortion. If the part of image is farther from the optical center, it will have the larger distortion. Thus the calibration along the image's long side will be more significant than that along the short side, eventually resulting in the image's aspect ratio changes when compare the calibrated image with the pre-calibration image. The extent of calibration reflected in the image is the extent of the pixels' stretching. When the stretching is too large, the image becomes blurred. As shown in Figure 20, the upper photograph is taken by the wide-angle lens and the bottom is the same image calibrated by algorithm. The edge area becomes blurred after calibration due to stretching. The output resolution can be set in the SDK.

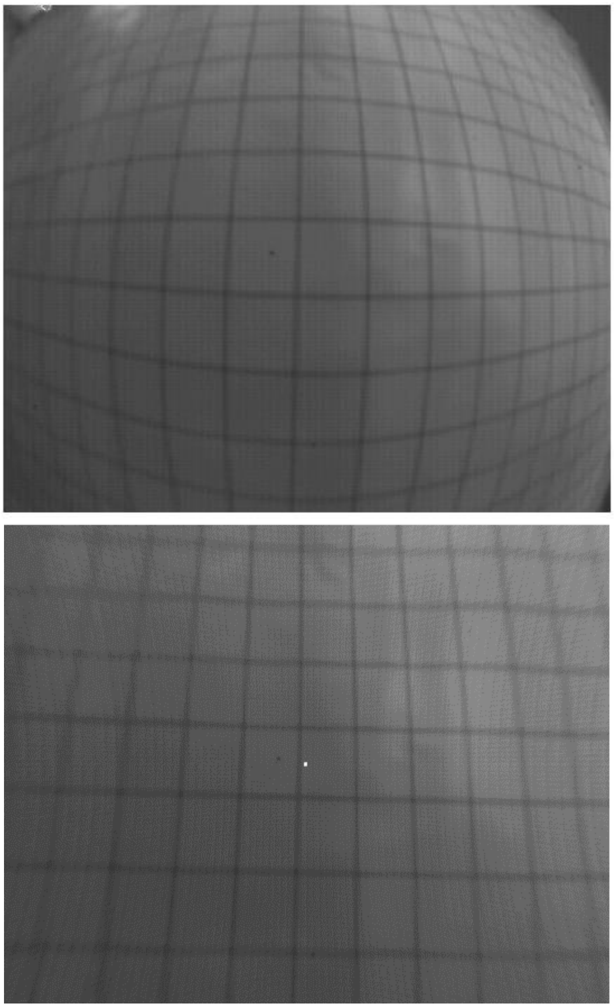


Figure 20 Photograph taken by the wide-angle lens (upper) and its calibrated result (bottom)

In the CE30-C, the LiDAR's direct output has an image resolution of 320 * 24 and the field of view of 132*9 °. After the calibration of SDK, the resolution has to be set to 660 * 24 to retain the field of view of 132 * 9 °.

11.3.SDK Output Data

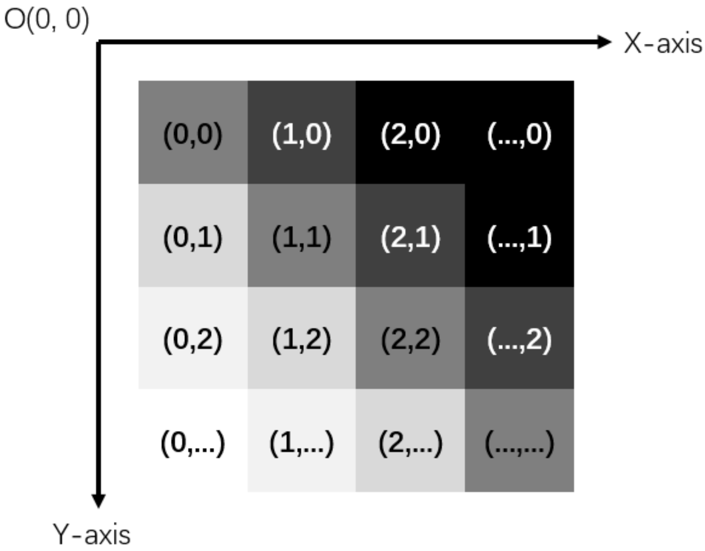


Figure 21 Illustration of data sequence

A frame of depth data is outputted from the SDK with the resolution that have been set. The data is arranged in form of one-dimensional array. The sequence is from left to right and top to bottom, and the pixel in the upper left corner of the image is the origin point. Output along X axis, then Y axis, the following output sequence will be generated as shown in the figure above:

(X,Y) : (0,0) (1,0) (2,0) (…,0) … (0,1) (1,1) (2,1) (…,1) … (0,2) (1,2) (2,2) (…,2) … (0,…) (1,…) (2,…) (…,…) …

The values indicate the distances from detected object to the plane of camera, it is expressed in cm by each pixel through the data format of 16-bit unsigned short int.

Please refer to the Operation Manual for details