Vzense
ToF sensor & application

Vzense DCAM Series ToF Camera

Accuracy and Precision Testing Data

Dec 2022

Revision 1.0

Revision History

Revision	Description	Date
1.0	• Initial Version	Dec 2022

Vzense
ToF sensor & application

Contents

1 Introduction

There are a variety of metrics that can be defined to evaluate depth quality. A common environment that is compatible with all tests is recommended to be used, such as a smooth and flat surface with a matt finish uniform, aligned parallel to the depth camera that is placed at a controllable and known distance from the camera under test. White or light color board mounted to a rigid frame or structure is a suitable target.

Depth data accuracy and precision (also called temporal noise) are the primary characteristics for judging the depth camera image quality.

Accuracy

Accuracy is the mean difference between the measured distance and the true distance (ground truth). It is a description of systematic absolute errors.

$$Accuracy = \frac{Measured\ distance - true\ distance}{true\ distance}$$

Precision

Precision is mostly defined as a standard deviation of accuracy. It is also called temporal noise or repeatability. Precision measures the variation in depth values over a specific number of frames.

$$Precision = standard\ deviation = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - u)^2}$$

The following diagrams illustrate the relation between the two aspects:

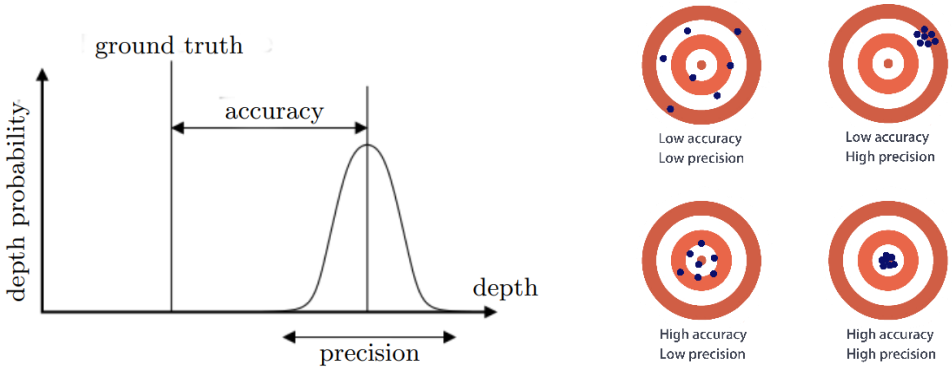


FIGURE 1: RELATION OF PRECISION AND ACCURACY

2 Test Condition

- Target: flat 80cm*80cm 40% reflectivity grey board mounted on bar attached to motion stage (*refer to figure 2*)
- Camera positioning: mounted on a steel fixture, laser distance meter used to measure distance from case front to the grey board
- Camera setting: camera warmed up for 20 minutes.
- Imaging environment: 22℃ room temperature, 200Lux room light on during testing, black curtain used on one side to minimize reflections around (*refer to figure 2*)
- Motion stage moves from 0.5meters to 6meters, and stopped in 0.5m, 1m,1.5m, 2m, 2.5m, 3m, 3.5m, 4m, 4.5m, 5m, 5.5m, 6m. During each step measure depth over 10×10 pixel ROI (region of interest) at image center, repeat 32 times at each position.
- Depth metrics are measured and recorded in real time by using the self-developed tool. For the evaluation of absolute depth values, we use the mean depth of the image set in each pixel. The standard deviation is computed based on the deviation in an image set.

FIGURE 2: 80CM*80CM 40% REFLECTIVITY TARGET & IMAGING ENVIRONMENT

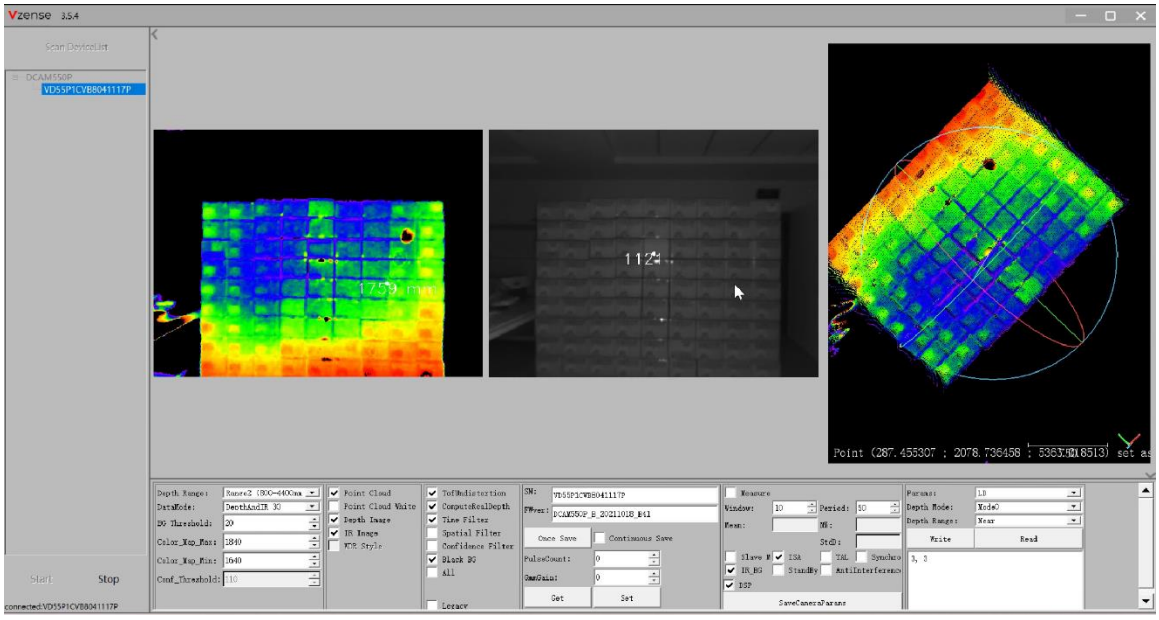


FIGURE 3: DEFAULT CAMERA SETTING

3 Introduction to DCAM Series

Vzense DCAM series features pulse iToF technology with 640*480 depth resolution and two infrared VCSEL emitters. DCAM series consists of a suite of cameras including DCAM550-P, DCAM550-U, DCAM550-E, and two RGB-D cameras, DCAM560C Pro and DCAM560C Lite.

The depth data produced by DCAM series is very helpful for a variety of market segments including mobile robotics, target recognition, etc. The depth data is calculated inside the camera and users can get point cloud via SDK from the host.

Besides depth data, DCAM560C Pro and DCAM560C Lite are configurated with a 1600*1200 resolution RGB sensor which provides acquisition of mapped RGB and depth images. Please refer to the DCAM series datasheet for the detailed description of these modules and their features. The difference between the models is listed below briefly.

Another advantage of DCAM series is the multiple choices of emitter's FOV and wavelength. The selectable FOV and wavelength are listed below.

Model	Selectable emitter's wavelength	Selectable emitter's FOV	Selectable RGB FOV
DCAM550-U/P/E	850nm	H69° V51°	No RGB
		H90° V69°	No RGB
		H100° V77°	No RGB
	940nm	H69° V51°	No RGB
		H90° V69°	No RGB
		H100° V77°	No RGB
DCAM560C Pro/Lite	850nm	H69° V51°	H77° V55°
		H90° V69°	H85° V70°
		H100° V77°	H85° V70°
	940nm	H69° V51°	H77° V55°
		H90° V69°	H85° V70°
		H100° V77°	H85° V70°

FIGURE 4: DCAM550 CONNECTORS

FIGURE 5: DCAM560C CONNECTORS

4 DCAM Series Accuracy and Precision Testing

To achieve a result as accurate as possible, Vzense cameras are calibrated at the factory and tested to guarantee a reliable accuracy. Vzense DCAM550 series cameras are calibrated for a measurement range of 0.35~6meters and DCAM560C series cameras for 0.16~6meters.

Precision measures the variation in depth values over a specific number of frames, so it is also called temporal noise or repeatability. The purpose of precision measurement is to understand the depth camera's time-dependent aspects of per pixel Z-accuracy. It is measured per pixel and then an average or median is taken over the ROI.

Relations between precision and distance

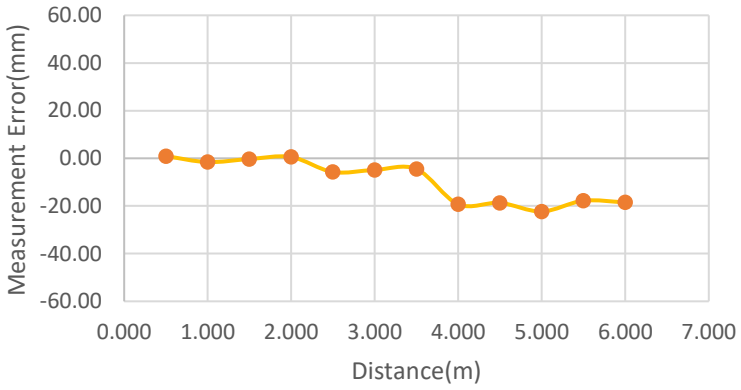
Following the test conditions described in Part 2, with the assistant of a self-developed software tool, average accuracy is measured over 10×10 pixels ROI at image center, repeat 32 times at each position then precision data as a standard deviation in depth values is calculated.

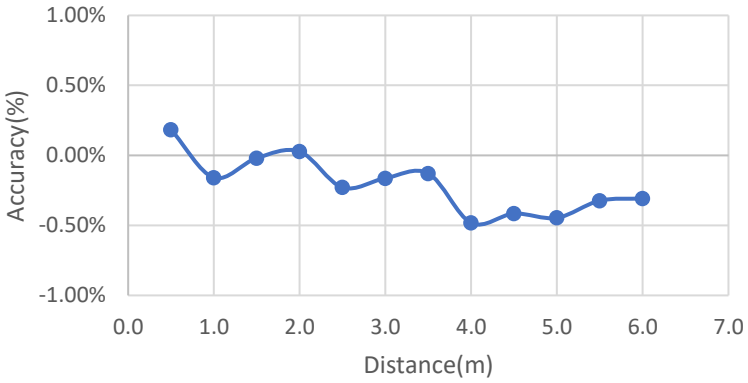
Test Result

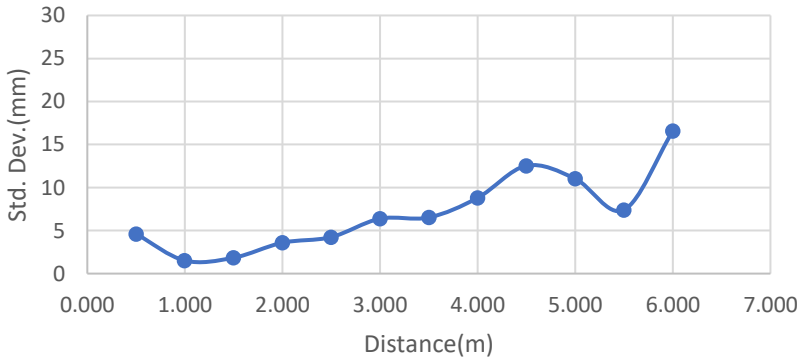
Below Table 2 shows the data of two units' mean measurement error and accuracy based on the test conditions listed above. Measurement Error keeps in millimeter or even submillimeter precise and accuracy is lower than 1%.

Test No.	Ground Truth (mm)	Camera setting range	Measure Error(mm)	Accuracy (%)	Std Dev. (mm)
1	500	0(160~1100mm)	0.92	0.184%	4.61
2	997	1(500~2800mm)	-1.58	-0.158%	1.52
3	1497	1(500~2800mm)	-0.30	-0.020%	1.84
4	1998	1(500~2800mm)	0.55	0.028%	3.59
5	2498	2(750~4500mm)	-5.72	-0.229%	4.24
6	2998	2(750~4500mm)	-4.89	-0.163%	6.38
7	3500	2(750~4500mm)	-4.51	-0.129%	6.52
8	4000	5(1000~6000mm)	-19.28	-0.482%	8.80
9	4499	5(1000~6000mm)	-18.71	-0.416%	12.54
10	4999	5(1000~6000mm)	-22.30	-0.446%	11.03
11	5498	5(1000~6000mm)	-17.79	-0.324%	7.40
12	6000	5(1000~6000mm)	-18.47	-0.308%	16.58

TABLE 1: ACCURACY TEST DATA


60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
Measurement Error(mm)
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
Distance(m)


1.00%
0.50%
0.00%
-0.50%
-1.00%
Accuracy(%)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Distance(m)


30
25
20
15
10
5
0
Std. Dev.(mm)
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
Distance(m)

5 More test Data reference in different environment

1 More data as supplement to the test result shown above

Saved images and data: RGB, IR, Depth, point cloud

Test target: flat 80cm*80cm 40% reflectivity grey board

Distance: 0.5~6meters

Ambient Light: room light from ceiling, ~200Lux

Download link:
https://drive.google.com/drive/u/1/folders/10TMFsnnYFVBjXfBpTjeyMMN8ynG73mn8

2 More data available:

https://drive.google.com/drive/u/1/folders/1J8pCTEVl_N0op7pFnilwwx5wGCfCapVx