

Vzense DS Series Time-of-Flight Camera

Depth Quality Testing Data



Dec 2022

Revision 2.0

Revision History

Revision	Description	Date
1.0	<ul style="list-style-type: none">Initial Version	Nov 2022

Contents

1	<i>Introduction</i>	4
2	<i>Test Condition</i>	5
3	<i>Introduction to DS Series</i>	7
4	<i>DS Series Accuracy Testing</i>	8
5	<i>DS Series Precision Testing</i>	10
	Relations between precision and distance	10
	Relations between precision and exposure time	11
6	<i>More test Data reference in different environment</i>	12
6.1	More data as supplement to the test result shown above	12
6.2	Items in a bin/box.....	12
6.3	Corn pile in a corner with sunlight	13
6.4	Neatly stacked boxes in a warehouse	13

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 or repeatability) 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.

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

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.

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

The following diagrams illustrate the relation between the two aspects:

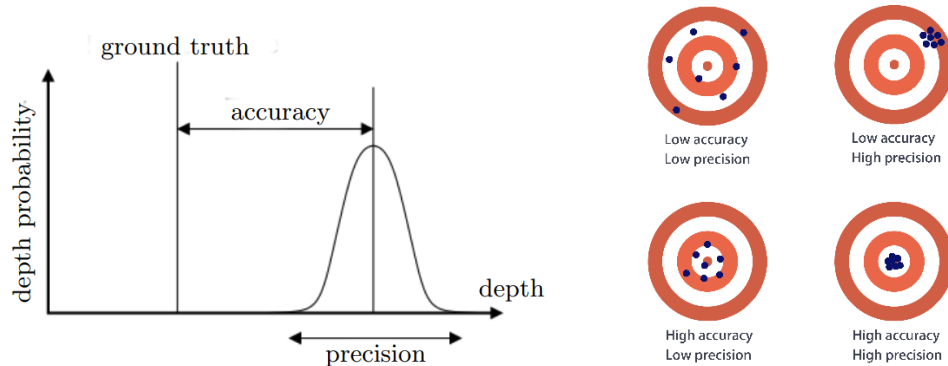


FIGURE 1: RELATION OF PRECISION AND ACCURACY

2 Test Condition

- Target: 80cm*80cm 40% reflectivity planar grey board mounted on bar attached to motion stage (*refer to figure 1*)
- Camera positioning: mounted on a steel fixture (*refer to figure 2*), laser distance meter used to measure distance from case front to the grey board
- Camera setting: default setting (*refer to figure 3*), camera warmed up for 20 minutes.
- Imaging environment: 22°C room temperature, 200Lux room light on during testing, black curtain used on one side to minimize reflections around (*refer to figure 1*)
- Motion stage moves from 0.4meters to 4.5meters, and stopped in 0.4m, 1m, 1.5m, 2m, 2.5m, 3m, 3.5m, 4m, 4.5m. 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: CAMERA MOUNTED ON THE FIXTURE

Control	ExposureTime	Image	Filter
WorkMode: <input type="button" value="ActiveMode"/>	ToF <input type="radio"/> Auto <input type="radio"/> Manual ExposureTime(us): <input type="text" value="1000"/>	<input checked="" type="checkbox"/> Depth <input checked="" type="checkbox"/> IR <input checked="" type="checkbox"/> RGB <input checked="" type="checkbox"/> Point Cloud <input type="checkbox"/> Point Cloud White <input type="checkbox"/> Point Cloud + RGB <input type="checkbox"/> ColorImgToDepthSensor <input type="checkbox"/> DepthImgToColorSensor	<input type="checkbox"/> All <input checked="" type="checkbox"/> Black BG <input checked="" type="checkbox"/> FillHole <input type="checkbox"/> Spatial Filter TimeFilter: <input type="text" value="1"/> <input checked="" type="checkbox"/> FlyingPixelFilter: <input type="text" value="15"/> <input checked="" type="checkbox"/> ConfidenceFilter: <input type="text" value="15"/> <input checked="" type="checkbox"/>
Depth ColorMap_Max: <input type="text" value="7495"/> Depth ColorMap_Min: <input type="text" value="1000"/> IRGmmGain: <input type="text" value="64"/> FrameRate: <input type="text" value="20"/> RGB Resolution: <input type="text" value="1600*1200"/>	RGB <input type="radio"/> Auto <input type="radio"/> Manual ExposureTime(us): <input type="text" value="0"/>	SaveImg: <input type="button" value="📷"/> Record: <input type="button" value="📹"/>	

FIGURE 4: DEFAULT CAMERA SETTING

3 Introduction to DS Series

Vzense DS series features Sony depthsense continuous wave iToF sensor with 640*480 depth resolution and two infrared VCSEL emitters. DS series consists of a suite of cameras including DS77 Pro, DS77 Lite and DS77C Pro, DS77C Lite.

DS series produces high quality depth data which is very helpful for a variety of market segments including mobile robotics, volumetric scanning, target recognition, etc. The depth data is calculated inside the camera and users can get point cloud via SDK from the host.

Besides, DS77C Pro and DS77C Lite are configured with a 1600*1200 resolution RGB sensor which provides acquisition of mapped RGB and mapped depth images. Please refer to the DS series datasheet for the detailed description of these modules and their features. The difference between the models is listed below briefly.

	RGB	PoE+	IP67
DS77 Pro		√	√
DS77 Lite			
DS77C Pro	√	√	√
DS77C Lite	√		

TABLE 0-1: DIFFERENCE OF DS SERIES MODELS



FIGURE 5: DS77 CONNECTORS



FIGURE 6: DS77C CONNECTORS

4 DS Series Accuracy Testing

To achieve a result as accurate as possible, Vzense cameras are calibrated at the factory and tested to guarantee a reliable accuracy. Vzense DS series cameras are calibrated for a measurement range of 0.4~4.5meters. Technically speaking, the camera is capable of measuring distances as minimal as 0.15meters so if users have quite near measurement requirement, we also offer products at a customized range.

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)	Mean Measurement Value (mm)	Mean Measure Error (mm)	Accuracy (%)
1	520	515.5	-4.50	-0.865%
2	620	616.8	-3.20	-0.516%
3	1118	1115.2	-2.80	-0.250%
4	1617.5	1614.3	-3.20	-0.198%
5	2620	2618.8	-1.20	-0.046%
6	3123	3118.2	-4.80	-0.154%
7	3621.5	3620.4	-1.10	-0.030%
8	4121	4120.1	-0.90	-0.022%
9	4620	4620.7	0.70	0.015%

Test No.	Ground Truth(mm)	Mean Measurement Value (mm)	Mean Measure Error (mm)	Accuracy (%)
1	400	401.6	1.6	0.400%
2	995	995.6	0.6	0.060%
3	1496	1494.4	-1.6	-0.107%
4	1997	1999.2	2.2	0.110%
5	2497	2500.4	3.4	0.136%
6	2998	2999.4	1.4	0.047%
7	3500	3500.1	0.1	0.003%
8	3999	3999.5	0.5	0.013%
9	4498	4511.6	2.2	0.049%

TABLE 0-2: ACCURACY TEST DATA

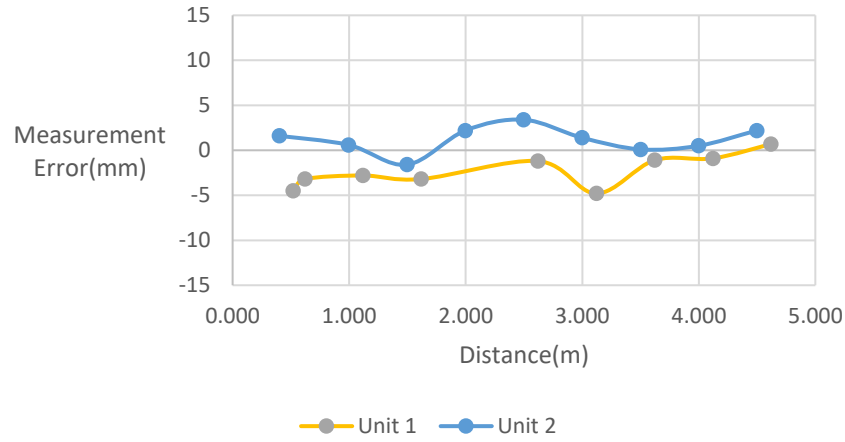


TABLE 3: MEASUREMENT ERROR IN DIFFERENT DISTANCE

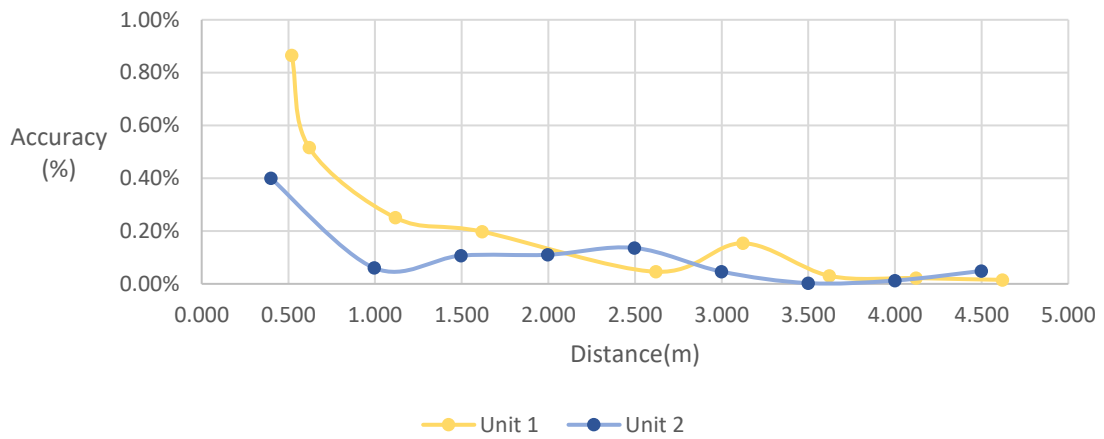


TABLE 4: ACCURACY IN DIFFERENT DISTANCE

5 DS Series Precision Testing

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.

Test Result

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 No.	Ground Truth(mm)	Mean Measurement Value (mm)	Precision (mm)
1	520	515.5	1.70
2	620	616.8	2.00
3	1118	1115.2	3.10
4	1617.5	1614.3	5.90
5	2620	2618.8	9.30
6	3123	3118.2	15.50
7	3621.5	3620.4	21.70
8	4121	4120.1	25.50
9	4620	4620.7	34.10

Test No.	Ground Truth(mm)	Mean Measurement Value (mm)	Precision (mm)
1	400	401.6	1.40
2	995	995.6	3.10
3	1496	1494.4	6.50
4	1997	1999.2	7.20
5	2497	2500.4	12.00
6	2998	2999.4	14.10
7	3500	3500.1	20.20
8	3999	3999.5	30.90
9	4498	4511.6	25.60

TABLE 5: PRECISION DATA IN DIFFERENT DISTANCE (EXPOSURE TIME @1MS DEFAULTED)

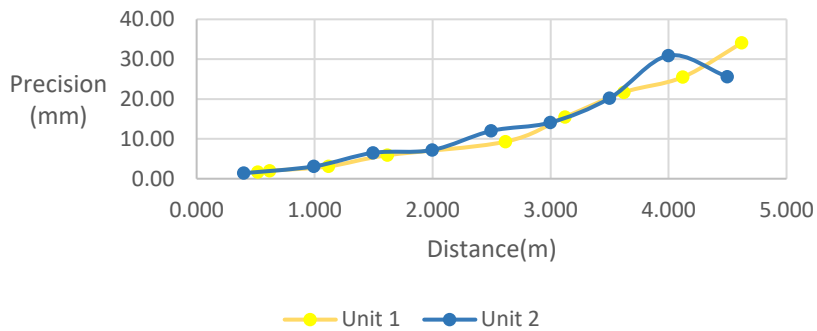
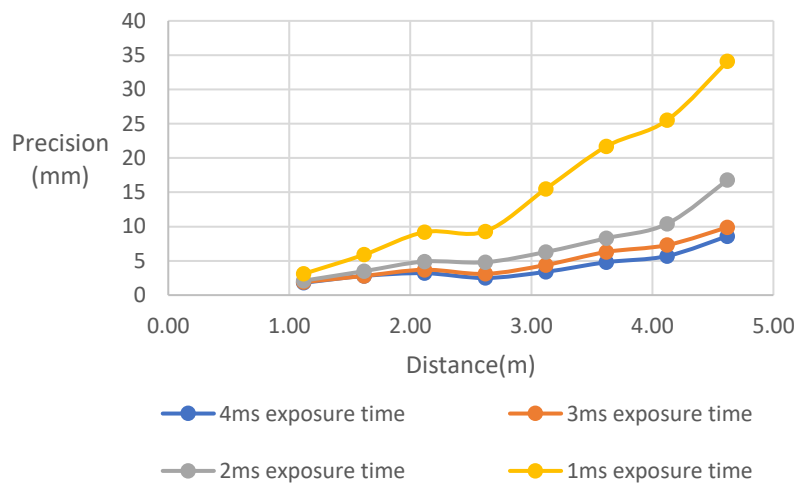


TABLE 6: PRECISION TREND IN DIFFERENT DISTANCE (EXPOSURE TIME @1MS DEFAULTED)

Relations between precision and exposure time

To help users understand the factors to influence precision, in each distance, we tested the precision with different exposure time setting at 1ms, 2ms, 3ms and 4ms. Below data shows that the longer exposure time the camera is set, the higher precision the camera can get, as long as images are not over exposure.



6 *More test Data reference in different environment*

6.1 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: 0.4~4.5meters

Ambient Light: room light from ceiling, ~200Lux

Download link:

<https://drive.google.com/drive/u/1/folders/1qegY4Q8aAEJBadKtlav7wiwfnY0Q-aEP>

Or <https://1drv.ms/u/s!Aq4U4G0CF3nChgSUSxSbvyFHBx1r?e=k1fKoe>



6.2 Items in a bin/box

Saved images and data: RGB, IR, Depth, point cloud, registered color to depth

Distance: 1.1~1.3meters

Test target: items in the bin and box including white boxes with/without poly films, packs of batteries, power strips in poly film, plastic bottles

Ambient Light: room light from ceiling, ~200Lux

Download link:

https://drive.google.com/drive/u/1/folders/1a0gW2Chb_oepI--g5xIAMCGX4AKJUI3P



6.3 Corn pile in a corner with sunlight

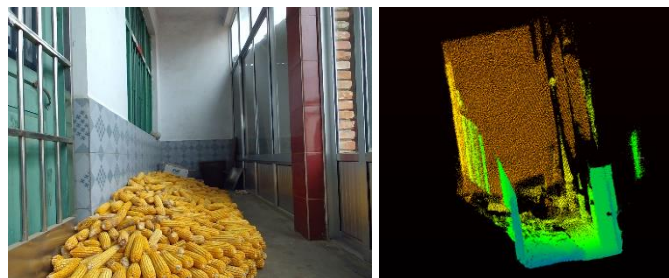
Saved images and data: RGB, IR, Depth, point cloud

Test target: corn pile

Ambient Light: sunlight, ~20,000Lux

Download link:

https://drive.google.com/drive/u/0/folders/1XOpmaScv-Uivulv_HbjRUTMQwmsVRnp?hl=zh-TW



6.4 Neatly stacked boxes in a warehouse

Saved images and data: Depth, point cloud

Distance: 1.7meters

Test target: stacked boxes

Ambient Light: room light from ceiling, ~300Lux

Download link:

https://drive.google.com/drive/u/0/folders/1yHFIClzsA0WAFGm3U8s1VitFs_yFaT?hl=zh-TW



6.5 Oranges in a basket

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

Distance: 0.8meters

Test target: oranges, a basket

Ambient Light: room light from ceiling, ~300Lux

Download link:

https://drive.google.com/drive/folders/1-U9emX2tRY-MNesUnnjsbHA9cVp4-6mE?usp=share_link



6.6 Felt materials letters on the table

Saved images and data: Depth, point cloud, IR, RGB, Color to depth

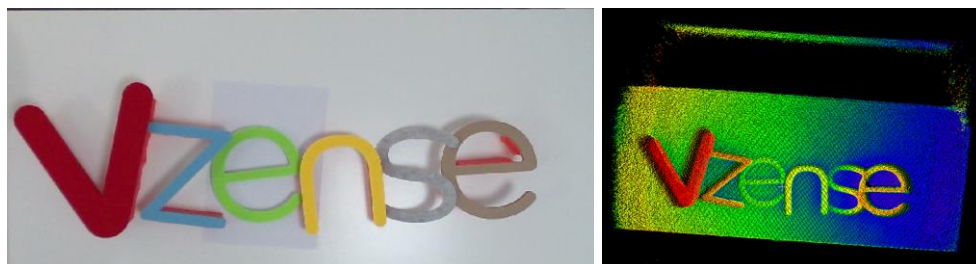
Distance: 0.8meters

Test target: Felt material letters

Ambient Light: room light from ceiling, ~300Lux

Download link:

https://drive.google.com/drive/folders/1ho359OFNbuNokf3YqLgWPNMbryJOgb66?usp=share_link



6.7 Black Tire

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

Distance: 1.5meters

Test target: black tire

Ambient Light: Garage, ~100Lux

Download link:

<https://1drv.ms/u/s!Aq4U4G0CF3nCi1dbDyuEV7T5TW3H?e=eNw5BL>



6.8 1.2m*1m Black plastic pallet outdoors

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

Distance: 2meters

Test target: 1.2m*1m black plastic pallet

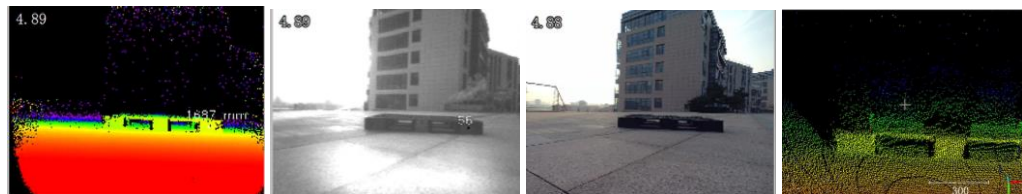
Ambient Light: Outdoors, ~10,000Lux sunlight

Download link:

<https://1drv.ms/u/s!Aq4U4G0CF3nCi0ZpvxddjOLRapnD?e=D4cFVf>

Or

https://drive.google.com/drive/folders/1ucP8hJHObEnB7kNvidxMh8XYBjPeESC8?usp=share_link



6.9 Silver Pipeline, grey bag, black board

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

Distance: 1-2meters

Test target: Silver Pipeline, grey bag, black board

Ambient Light: ~300Lux room light from ceiling

Download link:

<https://1drv.ms/u/s!Aq4U4G0CF3nCi3hhzITyYWe9uB8k?e=OOgRNW>

Or

https://drive.google.com/drive/folders/14VepdSZuH3RBWbcr9W9yAUp5hhl5iBhl?usp=share_link

