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INSTITUTO DE SISTEMAS E ROBÓTICA
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An experimental assessment of depth estimation performance for three different depth cameras technologies in transparent and refractive scenes

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Introduction

Consumer RGB-D cameras have been widely used in robotics and computer vision due to their compactness and ability to perform 3D reconstruction in real-time with a frame rate of 15-30 fps and resolutions up to 1280×720.

Cameras with different working principles will behave differently against possible known error sources such as background light, transparent and reflective materials, multi-path effect, etc. In our work, we only handle the transparency/refraction problem.

Case study cameras

ACTIVE SEREOSCOPY
(Intel RealSense D415)

LIDAR
(Intel RealSense L515)

STRUCTURED LIGHT
(Intel RealSense SR305)

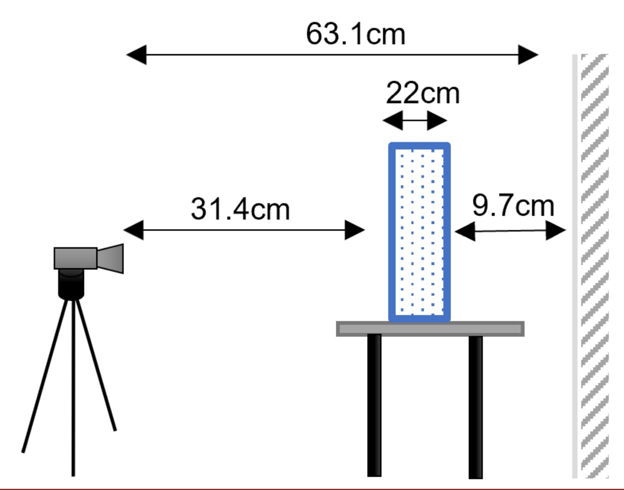
Objective

Evaluation of the depth estimation performance of three different technologies of range sensing in specific scenarios with transparency and refraction.

Methodology

SETUP

- 3 cameras with different technology;
- Dark room with adjustable LED board;
- Big glass aquarium (0.84×0.22×0.58cm);
- 100 acquisition depth frames with resolution 640x480 were acquired for each test.



TESTS

Wall

This is a zero test where we acquire depth images directly from the wall, that is, without any transparency between the camera and the wall.
These depth measurements will serve as a reference to the following tests since we don't have ground truth for the depth.

Empty

In this test, the aquarium is inserted between the camera and the wall. Therefore, we aim to analyze the influence of the two transparent glass walls of the aquarium (with air in-between) in the depth estimation.

Water Full

This test introduces another challenging scenario regarding transparency. The aquarium is filled with water (about 95L). Then, between the camera and the wall, we have a first glass wall, water, a second glass wall and air.

Water milk 1/2/3/4

The water is dyed with milk to experience different levels of transparency. **water milk1** is the less opaque of the four, with a milk concentration of 0,03% (V=V%). Then, **water milk2** with 0,13% (V=V%) and **water milk3** with 0,24% (V=V%). The most opaque solution, **water milk4** with 1,13% (V=V%).

EVALUATION

1 Qualitative analysis of depth distribution

In order to qualitatively evaluate the distribution of depth along the different materials with transparency/translucency (glass, water and water and milk solution), all the 100 acquisitions from each test were used. Having the point clouds, we estimated the average depth (i.e., the z coordinate) for each point from the 100 samples. To exclude non-stable depth values, we exclude estimations having less than 80 positive depth values out of 100 measurements. This data analysis allows us to qualitatively analyze the estimation of depth, function of the material.

2 Depth estimation failure rate

One way to evaluate the sensors performance is through the number of points per image where the cameras failed to estimate depth. Therefore, the evaluation of the invalid points was conducted as follows:

- For each experiment two Region of Interest (RoI) were segmented - the right band (rb) and the left band (lb). The choice of having two different regions comes from we could study an area that corresponds to the black card on the wall and another that corresponds only to the white wall. Thus, the left band is a RoI with a black background (a cardboard) and the right band is a RoI with a white background (the wall). These areas were carefully picked in a frame. Only a frame of 100 was used to select the two RoIs and then they were the same for all the frames of the same acquisition;
- For each of the 100 samples, the points in the RoIs whose depth estimation failed were counted and the percentage of invalid points was obtained. Then, the average of the 100 percentages for each experiment was estimated.

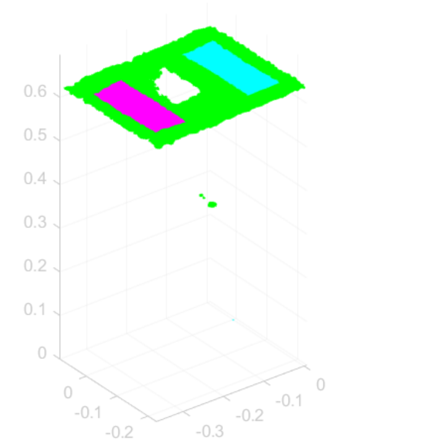


Figure 1 - Point Cloud with segmented bands. The left band is colored in magenta and the right band is colored in cyan.

Results

1

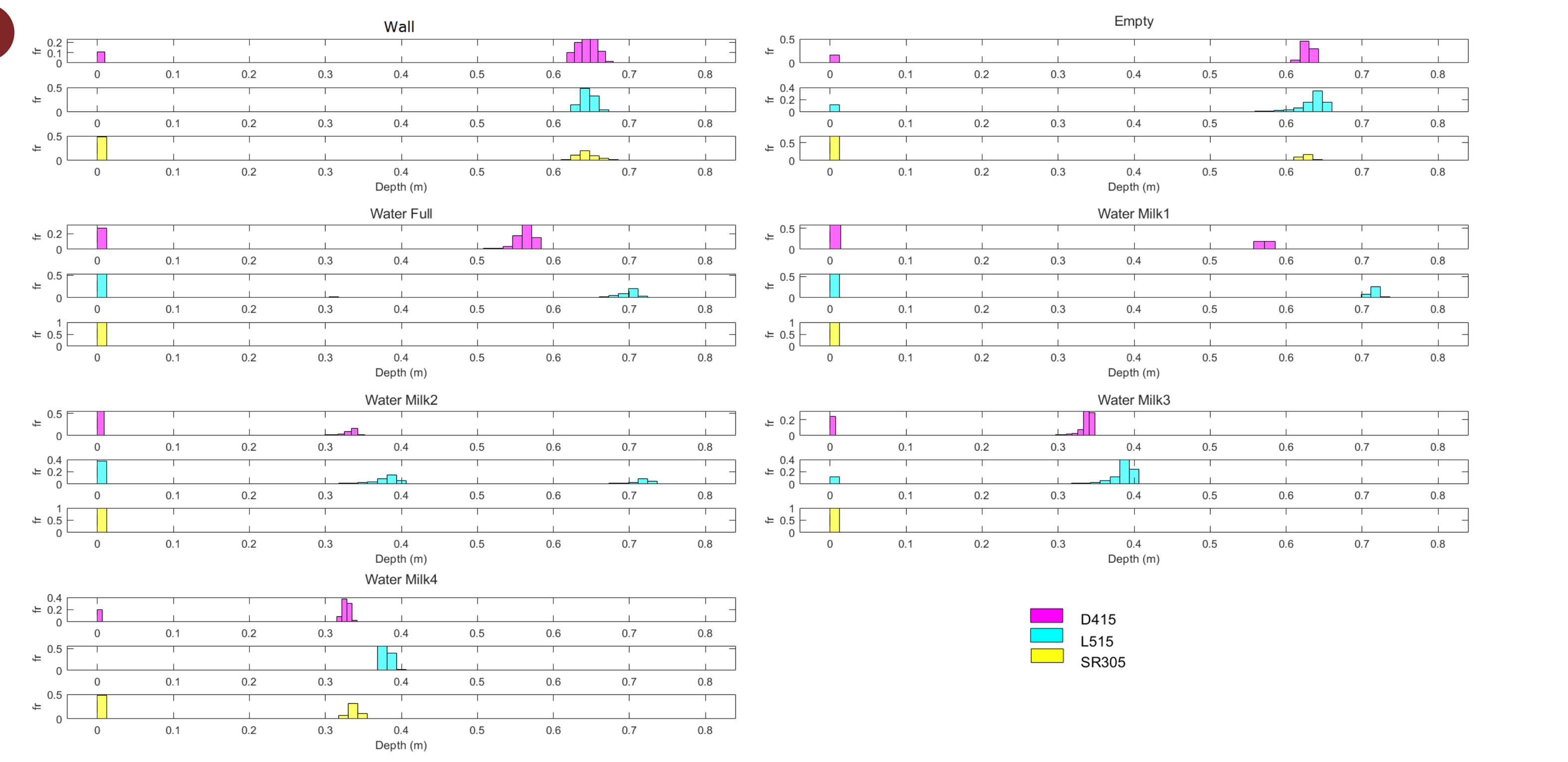


Figure 2 - Histograms for each acquisition (allowing a comparison between cameras): each histogram represents the relative frequency for each average depth value estimated by each camera.

2

	$D415_{wall}$	$D415_{empty}$	$D415_{water\_full}$	$D415_{water\_milk1}$	$D415_{water\_milk2}$	$D415_{water\_milk3}$	$D415_{water\_milk4}$
$\bar{f\%}_{rb}$ [1]	0.0041	0.0150	0.0177	0.0001	37.9954	0.6936	0.0000
$\bar{f\%}_{lb}$ [2]	0.0000	0.0011	0.2806	81.4556	2.3833	1.0275	0.0147

	$L515_{wall}$	$L515_{empty}$	$L515_{water\_full}$	$L515_{water\_milk1}$	$L515_{water\_milk2}$	$L515_{water\_milk3}$	$L515_{water\_milk4}$
$\bar{f\%}_{rb}$ [1]	0.0000	0.0000	0.0321	1.4239	87.9116	2.5124	0.0000
$\bar{f\%}_{lb}$ [2]	0.0014	8.0577	99.8891	99.9018	0.7502	0.0417	0.0000

	$SR305_{wall}$	$SR305_{empty}$	$SR305_{water\_full}$	$SR305_{water\_milk1}$	$SR305_{water\_milk2}$	$SR305_{water\_milk3}$	$SR305_{water\_milk4}$
$\bar{f\%}_{rb}$ [1]	0.0000	0.0021	100.0000	100.0000	100.0000	100.0000	0.0378
$\bar{f\%}_{lb}$ [2]	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	0.0198

[1] $\bar{f\%}_{rb}$ - Average of percentage of *invalid points* regarding the RoI *right band (rb)*.
[2] $\bar{f\%}_{lb}$ - Average of percentage of *invalid points* regarding the RoI *left band (lb)*.

Table 1 – Ave rage percentage of invalid points for the *right band* and the *left band*.

Conclusions

- This work describes a comparison between different depth cameras technologies in the case of transparency and refraction.
- We have presented an experimental framework to evaluate the estimation of depth with a scenario composed by a glass aquarium and semitransparent liquids.
- Comprehensive results were obtained demonstrating that the D415 camera yields better depth estimates in the case of transparent objects.

Acknowledgements

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