REPORT
SENSOR - REALSENSE CAMERA D435
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1. Sensor Selection

Sensor Chosen: Intel RealSense D435 RGB-D Camera
The D435 combines a standard RGB camera with a depth sensor that uses infrared technology to capture depth information.

2. Data Sheet Analysis

In this section, you'll summarize the key specifications of the Intel RealSense D435 based on its datasheet. Here are some key points to include:

- **Range**: 0.1 m to 10 m
- **Resolution**: Up to 1280 × 720 at 30 FPS for depth
- **Measurement Accuracy**: ±1% at 2 meters
- **Operating Conditions**:
    - Temperature: 0°C to 35°C
    - Field of view (FOV): 87° × 58° × 95° (depth sensor)
    - Power consumption: 1.6 W

3. Parameter Identification

Based on the datasheet, important parameters to focus on include:

- **Range**: 0 to 100 cm experiment and maximum distance for objects.
- **Resolution**: 1100 * 680 at 30 FPS.
- **Measurement Accuracy**: 2 - 5%
- **Environmental Conditions**: Different light levels and surface types affect the sensor's performance.

4. Theoretical questions coming to the experiment

i. Objects Less Than 13 cm in Height and Field of View (FoV):

- **Field of View (FoV) Limitation:** A stereo camera operates based on a specific field of view, forming a cone shape where the depth perception is most effective. If the mounting height of the camera is 13 cm, then objects that are lower than this height might not be fully captured within the FoV of the cone.

- **Why this happens:** Since the cone-shaped projection from the stereo camera is angled, objects positioned too close or below the camera's height (i.e., <13 cm) fall outside the detection zone of the camera. Stereo cameras rely on matching pixel data from two views (left and right). If an object is too near or below the camera's line of sight, there's insufficient data overlap between the two views to compute depth reliably.
- **Result:** These small or near objects can be effectively "invisible" to the camera as they are not captured well in the stereo matching process.

ii. Transparent Objects (Empty Glass):

- **Ray Passing Through Glass:** A stereo camera determines the depth of an object by matching corresponding points between the left and right image. Transparent objects like empty glass allow light to pass through, which means the camera sees the background or other objects behind the glass, making it difficult to calculate the depth of the glass itself.
- **Why this happens:** The transparent nature of the glass creates a mismatch in what the left and right cameras perceive, leading to an incomplete or incorrect disparity map. Since the disparity map is crucial for calculating depth, any mismatch or lack of corresponding points makes it impossible for the stereo camera to measure the depth of such transparent objects.
- **Result:** The glass object may not be detected or may appear distorted, as the stereo camera cannot effectively discern its edges or surface.

iii. Glass Filled with Water (Refraction Effect):

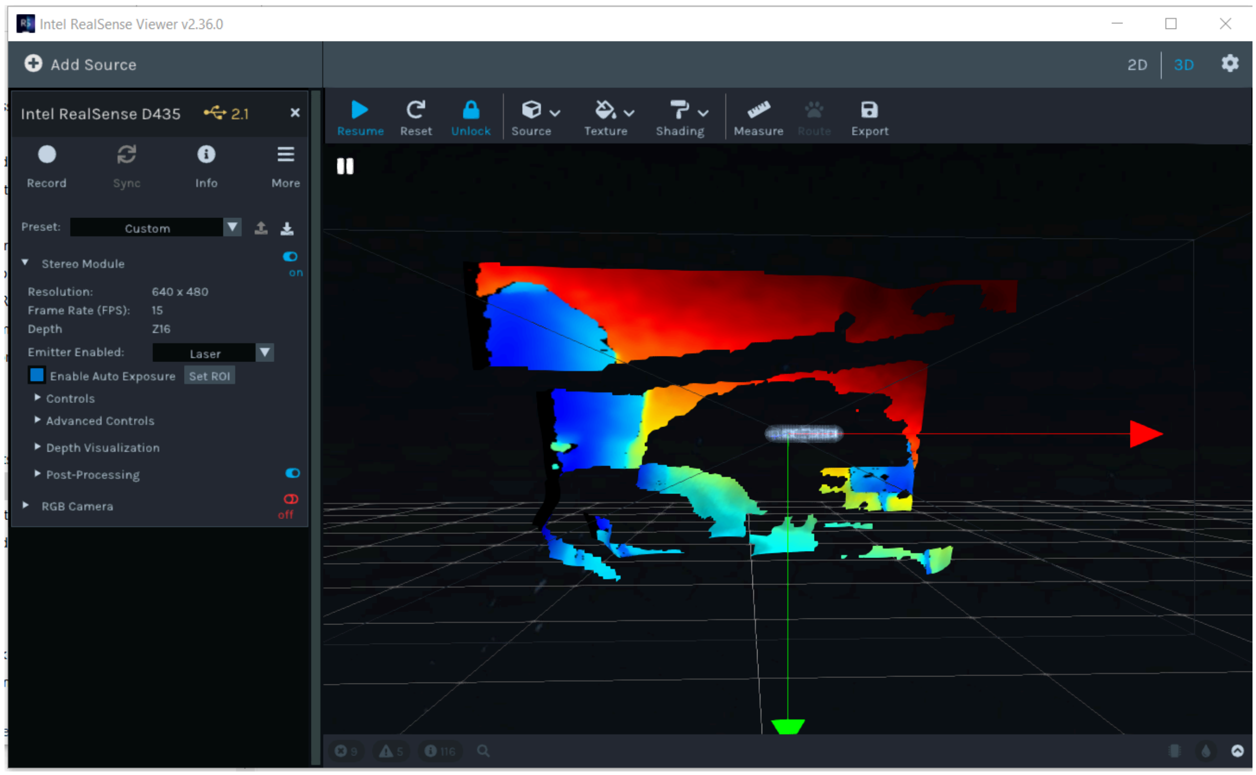
- **Ray Refraction in Water:** When light passes through water-filled glass, it undergoes refraction (bending), as the light changes direction when it moves from air to water and vice versa. This causes the rays entering the stereo camera to be deviated from their original paths.
- **Why this happens:** The refraction of light distorts the stereo matching process because the rays that the stereo camera captures are not from the expected straight-line paths. The left and right camera images will show displaced points for the same object due to refraction, and this results in significant difficulty in calculating accurate depth information.
- **Result:** The stereo camera will struggle to detect the true position or depth of the water-filled glass. The calculated disparity map will be inaccurate due to the shifted light rays, making depth perception inconsistent or incorrect.

5. Experimental Setup

Intel RealSense Viewer was downloaded and set up on Windows. Our experimental set up contained:

1. Intel RealSense D435 RGB-D Camera
2. Windows Laptop
3. Measuring tape
4. White glue bottle
5. A clear glass

The camera was connected to the laptop and the app was configured. Measurements were taken by clicking on the object from the application which displays the distance to the object.



6. Experimental Results and Analysis

i. Glue Bottle Measurements

We conducted measurements using the RealSense D435 camera on a glue bottle at various distances. Here are the results:

Actual Distance (cm)	Measured Distance (cm)	Absolute Error (cm)	Relative Error (%)
10	0	10	100

15	0	15	100
20	19.9	0.1	0.5
30	29.9	0.1	0.33
40	40	0	0
60	60.3	0.3	0.5
70	70.6	0.6	0.86
90	91.2	1.2	1.33
100	100.18	0.18	0.18
405	399	-	-

Analysis:

1. **Minimum Detection Distance:** The camera failed to detect the object at 10 cm and 15 cm. This suggests that the minimum detection distance for this setup is between 15 cm and 20 cm.
2. **Accuracy:** For distances between 20 cm and 100 cm, the camera shows high accuracy with relative errors mostly below 1%. The highest relative error in this range is 1.33% at 90 cm.
3. **Long-Range Performance:** At 405 cm the glue bottle disappears and the RGBD camera is no longer able to detect it.
4. **Consistency:** The measurements show good consistency across the range, with errors generally increasing with distance, as expected.
5. **Comparison to Datasheet:** The measurements align well with the datasheet specifications. The accuracy is within the stated ±1% at 2 meters for most measurements.

ii. Glass Object without Water

Measurements were also taken for a glass object without water:

Actual Distance (cm)	Measured Distance (cm)	Absolute Error (cm)	Relative Error (%)
10	0	10	100
15	0	15	100

20	0	20	100
30	32.4	2.4	8
40	43.5	3.5	8.75
50	56.2	6.2	12.4
70	N/A	N/A	N/A

Analysis:

1. **Transparency Issues:** The camera failed to detect the glass object at distances of 10 cm, 15 cm, and 20 cm. This aligns with our earlier observation about transparent objects being difficult for the camera to detect.
2. **Inaccurate Measurements:** When the camera did detect the glass object (30 cm to 50 cm), the measurements were significantly less accurate compared to the glue bottle. Relative errors ranged from 8% to 12.4%, which is much higher than the expected 2-5% range.
3. **Inconsistent Detection:** The measurement at 70 cm is missing, which could indicate that the camera failed to detect the object at this distance.
4. **Overestimation:** When detected, the camera consistently overestimated the distance to the glass object. This could be due to the transparent nature of the object affecting the camera's depth perception.

7. Conclusions

1. **Opaque Objects:** The RealSense D435 camera performs very well with opaque objects like the glue bottle, showing high accuracy within its specified range.
2. **Minimum Detection Distance:** The camera has a minimum detection distance between 15 cm and 20 cm for opaque objects.
3. **Transparent Objects:** The camera struggles significantly with transparent objects, showing either no detection or inaccurate measurements. This aligns with our theoretical understanding of how RGBD cameras work with transparent materials.
4. **Range:** The camera shows good performance up to at least 4 meters for opaque objects, which is well within its specified range of 0.1 m to 10 m.
5. **Accuracy:** For opaque objects, the camera's accuracy is generally within the specified ±1% at 2 meters. However, for transparent objects, the accuracy is much lower and outside the specified range.

These experimental results confirm our earlier observations about the camera's limitations with transparent objects and objects below a certain height. They also demonstrate the camera's high performance with opaque objects within its specified range.

8. Experimental pictures

Fig.1. Water Bottle

Fig.2. Empty Glass

Fig.3. Water Bottle

Fig.4. Opaque Object