

RESULTS

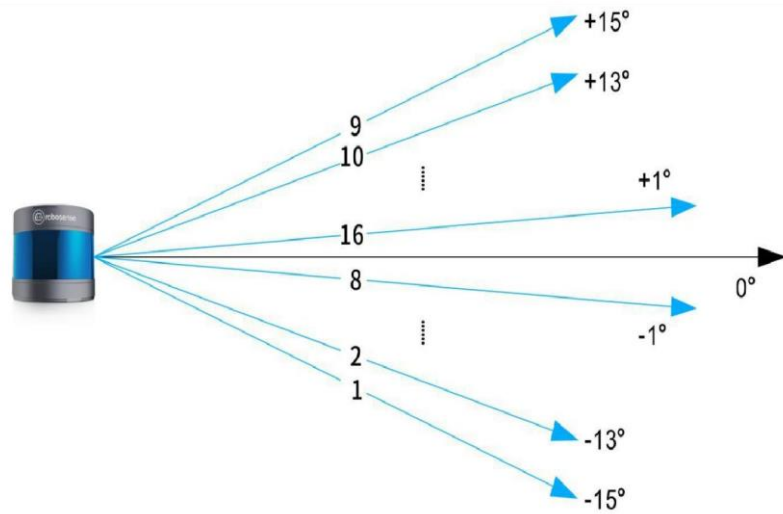
EXPERIMENTAL ASSESSMENT OF THE RS-LiDAR16 LIDAR SENSOR

Génération Robots

01/09/19

| Lidars | RS-LiDAR16 | Quanergy M8-1 | Sick TIM551-2050001 | RPLIDAR A3 |
|-------------------------------|-------------------|------------------|---------------------|---|
| Type | 3D | 3D | 2D | 2D |
| Range (80% reflectivity) | 0.2 ~ 150m | 1 ~ 150m | 0.05 ~ 10m | 0.15 ~ 10m |
| Horizontal angular range | 360° | 360° | 270° | 360° |
| Horizontal Angular resolution | 0.09 ~ 0.36° | 0.03 ~ 0.2° | 1° | 0.225° ~ 0.36° |
| Vertical angular range | 30° (-15° ; +15°) | 20° (-17° ; +3°) | x | x |
| Vertical resolution | 2° | 2.5° | x | x |
| Scanning frequency | 5 ~ 20Hz | 5 ~ 30Hz | 15Hz | 5 ~ 20Hz |
| Accuracy | ±2cm | ±3cm | ±6cm | Distance < 1.5m : < 0.5mm Distance > 1.5m : < 1% |

Lidars specifications announced



RS-LiDAR16



Quanergy



Sick TIM551



RPLiDAR A3

Test 1 : Materials influence on RS-LiDAR16

| | |
|-----------------------|--------------------|
| Lidar | RS-LiDAR16 |
| Scanning Frequency | 10Hz |
| Rotational speed | 600 rpm |
| Bag duration | 29.59 seconds |
| Bag Samples | 299 scans |
| Horizontal resolution | 0.18° |
| Points | NaN points removed |

Lidar parameter table

Distance 2.00 ± 0.01 m

Considering a static scene, the RS-LiDAR16 is positioning in front of a different material obstacles, at a distance of approximately 2m ± 0.01m. For each material, the lidar is launched in an indoor environment after at least 2 minutes of non-use for 3 minutes. A 30 seconds bag is recorded for data post-process.

Ten materials : window, TV screen (glass), white board, door, foam, transport plastic, cardboard box, iron, wall, condensed wood.

| Beam | Parameters | Window | TV screen (glass) | White Board | Door | Foam chair |
|----------|------------------|---------------|--------------------------|--------------------|-------------|-------------------|
| 8 | Number of values | 4 | 63 | 59 | 63 | 32 |

| | | | | | | |
|-----------|--------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 8 | Mean | 1.98 m | 1.99 m | 1.99 m | 2.01 m | 2.01 m |
| 8 | Range | 3.5 cm | 6.4 cm | 6.07 cm | 3.95 cm | 3.53 cm |
| 8 | Standard Deviation | 0.69 cm | 3.05 cm | 2.81 cm | 1.80 cm | 1.44 cm |
| 8 | Variance | 0.005 cm ² | 0.09 cm ² | 0.08 cm ² | 0.03 cm ² | 0.002 cm ² |
| 16 | Number of values | 3 | 64 | 60 | 63 | 61 |
| 16 | Mean | 1.94 m | 1.98 m | 1.98 m | 2.00 m | 1.99 m |
| 16 | Range | 74.9 cm | 2.14 cm | 1.06 cm | 1.67 cm | 4.29 cm |
| 16 | Standard Deviation | 0.63 cm | 0.73 cm | 0.4 cm | 0.6 cm | 1.82 cm |
| 16 | Variance | 0.004 cm ² | 0.005 cm ² | 0.002 cm ² | 0.004 cm ² | 0.033 cm ² |

Distance 2.00 ± 0.01 m

| Beam | Parameters | Transport plastic | Cardboard box | Iron | Wall | Condensed wood |
|------|--------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 8 | Number of values | 62 | 63 | 60 | 24 | 62 |
| 8 | Mean | 2.05 m | 2.04 m | 2.07 m | 2.07 m | 2.07 m |
| 8 | Range | 3.53 cm | 3.63 cm | 3.94 cm | 4.50 cm | 5.80 cm |
| 8 | Standard Deviation | 1.33 cm | 1.56 cm | 1.54 cm | 0.69 cm | 2.90 cm |
| 8 | Variance | 0.02 cm ² | 0.024 cm ² | 0.024 cm ² | 0.005 cm ² | 0.008 cm ² |
| 16 | Number of values | 62 | 61 | 62 | 52 | 61 |
| 16 | Mean | 2.06 m | 2.02 m | 2.04 m | 2.08 m | 2.07 m |
| 16 | Range | 2.13 cm | 2.90 cm | 4.2 cm | 2.08 cm | 1.78 cm |
| 16 | Standard Deviation | 0.90 cm | 0.82 cm | 1.76 cm | 0.75 cm | 0.70 cm |
| 16 | Variance | 0.008 cm ² | 0.007 cm ² | 0.03 cm ² | 0.006 cm ² | 0.005 cm ² |

Test 2 : Light influence on RS-LiDAR16

| | |
|-----------------------|--------------------|
| Lidar | RS-LIDAR16 |
| Scanning Frequency | 10Hz |
| Rotational speed | 600 rpm |
| Bag duration | 29.59 seconds |
| Bag Samples | 299 scans |
| Horizontal resolution | 0.18° |
| Points | NaN points removed |

Lidar parameter table

Distance 2.00 ± 0.01 m

Considering a static scene, the RS-LiDAR16 is positioning in front of a planar wall (**condensed wood**) , at a distance of approximately **2 m \pm 0.01m**. For each environment, the lidar is launched after at least 2 minutes of non-use for 3 minutes. A 30 seconds bag is recorded for data post-process. **Four environments** : inside in total dark environment, inside with artificial lamps, outside in the shade and outside under the sun.

| Beam | Parameters | Dark | Artificial lamp | Sunlight in shade | Direct sunlight |
|-----------|--------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 8 | Number of values | 61 | 70 | 63 | 58 |
| 8 | Mean | 1.97 m | 1.97 cm | 2.05 m | 2.07 m |
| 8 | Range | 4.4 cm | 5.00 cm | 5.51 cm | 4.29 cm |
| 8 | Standard Deviation | 2.14 cm | 2.51 cm | 2.86 cm | 1.96 cm |
| 8 | Variance | 0.05 cm ² | 0.006 cm ² | 0.08 cm ² | 0.04 cm ² |
| 16 | Number of values | 62 | 70 | 30 | 31 |
| 16 | Mean | 1.96 m | 1.97 | 2.08 m | 2.08 cm |
| 16 | Range | 1.27 cm | 1.24 cm | 0.77cm | 1.22 cm |
| 16 | Standard Deviation | 0.47 cm | 0.45 cm | 0.34 cm | 0.55 cm |
| 16 | Variance | 0.002 cm ² | 0.002 cm ² | 0.001 cm ² | 0.003 cm ² |

Test 3 : Time drift and temperature influences on RS-LiDAR16

| | |
|---------------------------------|--------------------|
| Lidar | RS-LiDAR16 |
| Scanning Frequency | 10Hz |
| Rotational speed | 600 rpm |
| Bag duration | 59.59 seconds |
| Bag Samples | 597 scans |
| Horizontal resolution | 0.18° |
| Points | NaN points removed |
| ambient temperature under shade | +25°C |
| ambient temperature under sun | +32°C |

Lidar parameter table

Shade - Distance 2.00 ± 0.01 m

Considering a static scene, the RS-LiDAR16 is positioning in front of a planar wall (**condensed wood**), at a distance of approximately **2m ± 0.01m**. For each environment, the lidar is launched after at least 10 minutes of non-use for 45 minutes. Every 10 minutes a 1 minute bag is recorded for data post-process.

Two environments : Outside in the shade (ambient temperature ~ 25°C) and outside under the sun (contact temperature ~ 32°C).

| Beam | Parameters | 0 min | 10 min | 20 min | 30 min | 35 min | 40 min | 45 min |
|------|--------------------|-----------------------|-----------------------|-----------------------|----------------------|----------------------|----------------------|----------------------|
| 8 | Number of values | 63 | 63 | 63 | 61 | 60 | 56 | 63 |
| 8 | Mean | 2.05 m | 2.02 m | 2.01 m | 2.01 m | 2.01 | 2.00 m | 2.01 m |
| 8 | Range | 5.51 cm | 5.22 cm | 5.51 cm | 5.48 cm | 4.40 cm | 5.54 cm | 5.81 cm |
| 8 | Standard Deviation | 2.87 cm | 2.64 cm | 2.81 cm | 2.80 cm | 2.76 cm | 2.84 cm | 3.01 cm |
| 8 | Variance | 0.08 cm ² | 0.007 cm ² | 0.008 cm ² | 0.08 cm ² | 0.08 cm ² | 0.08 cm ² | 0.09 cm ² |
| 16 | Number of values | 30 | 62 | 62 | 61 | 61 | 56 | 62 |
| 16 | Mean | 2.08 m | 2.05 m | 2.04 m | 2.04 m | 2.04 m | 2.04 m | 2.05 m |
| 16 | Range | 0.78 cm | 3.37 cm | 3.25 cm | 3.05 cm | 3.03 cm | 3.35 cm | 4.25 cm |
| 16 | Standard Deviation | 0.34 cm | 1.57 cm | 1.51 cm | 1.39 cm | 1.39 cm | 1.56 cm | 2.12 cm |
| 16 | Variance | 0.001 cm ² | 0.02 cm ² | 0.02 cm ² | 0.02 cm ² | 0.02 cm ² | 0.02 cm ² | 0.05 cm ² |

Sunlight - Distance 2.00 ± 0.01 m

We took the beams 6 and 7 because the lidar had an offset on horizontal plane. Those beams match with beam 8 and 16 of previous test.

| Beam | Parameters | 0 min | 10 min | 20 min | 30 min | 35 min | 40 min | 45 min |
|------|--------------------|-----------------------|----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 6 | Number of values | 58 | 63 | 59 | 61 | 62 | 61 | 62 |
| 6 | Mean | 2.07 m | 2.06 m | 2.05 m | 2.05 m | 2.05 m | 2.06 m | 2.05 m |
| 6 | Range | 4.29 cm | 1.72 cm | 2.19 cm | 2.70 cm | 2.92 cm | 3.07 cm | 3.97 cm |
| 6 | Standard Deviation | 1.96 cm | 0.57 cm | 0.78 cm | 0.99 cm | 1.08 cm | 1.17 cm | 1.67 cm |
| 6 | Variance | 0.04 cm ² | 0.03 cm ² | 0.006 cm ² | 0.01 cm ² | 0.02 cm ² | 0.01 cm ² | 0.03 cm ² |
| 7 | Number of values | 61 | 61 | 59 | 61 | 62 | 61 | 62 |
| 7 | Mean | 2.08 m | 2.08 m | 2.07 m | 2.07 cm | 2.07 cm | 2.08 m | 2.07 m |
| 7 | Range | 1.22 cm | 4.15 cm | 2.57 cm | 1.89 cm | 1.85 cm | 1.73 cm | 1.97 cm |
| 7 | Standard Deviation | 0.55 cm | 1.83 cm | 0.95 cm | 0.66 cm | 0.68 cm | 0.61 cm | 0.70 cm |
| 7 | Variance | 0.003 cm ² | 0.03 cm ² | 0.009 cm ² | 0.004 cm ² | 0.005 cm ² | 0.003 cm ² | 0.004 cm ² |

Test 4 : Part of Angular range influences on RS-LiDAR16

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|-----------------------|--------------------|
| Lidar | RS-LIDAR16 |
| Scanning Frequency | 5HZ |
| Rotational speed | 300 rpm |
| Bag duration | 14,67 seconds |
| Bag Samples | 74 scans |
| Horizontal resolution | 0.09° |
| Points | NaN points removed |

Lidar parameter table

Phase offset - Distance 1.01 ± 0.01 m

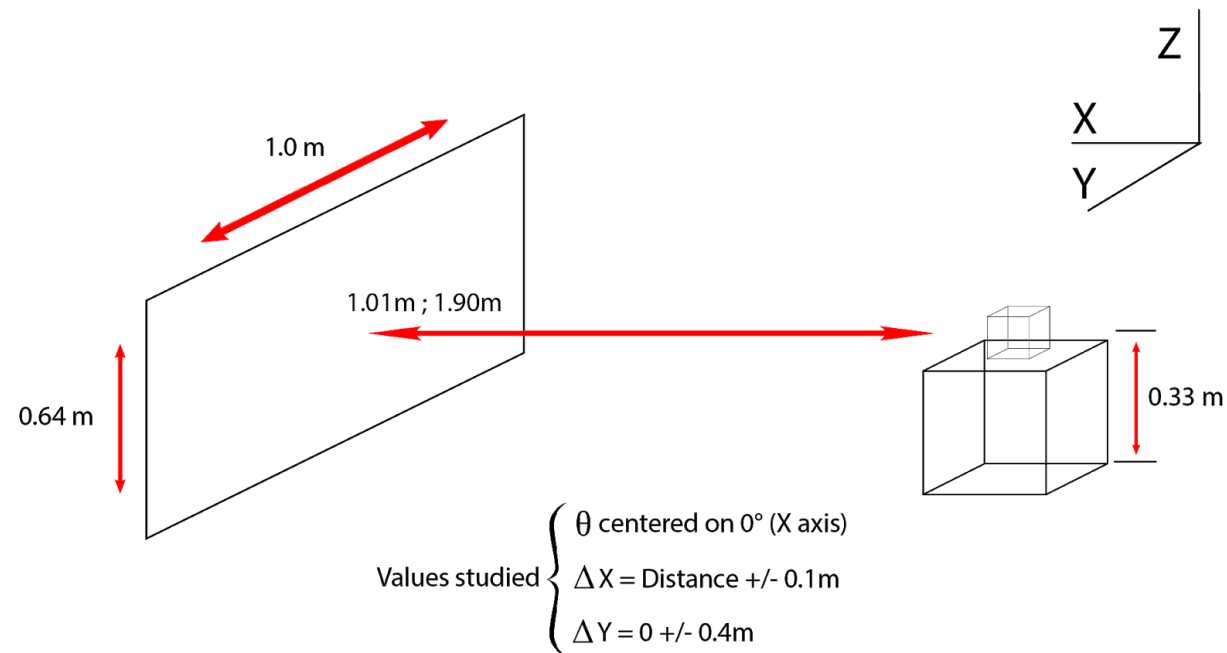
| Beam | Parameters | Phase offset 0° | Phase offset +90° | Phase offset +180° | Phase offset +270° |
|----------|------------------|------------------------|--------------------------|---------------------------|---------------------------|
| 8 | Number of values | 232 | 251 | 234 | 250 |
| 8 | Mean | 1.01 m | 1.02 m | 1.01 m | 1.03 m |
| 8 | Range | 5.19 cm | 5.37 cm | 11.3 cm | 4.52 cm |

| | | | | | |
|-----------|--------------------|----------------------|----------------------|----------------------|----------------------|
| 8 | Standard Deviation | 2.72 cm | 2.75 cm | 2.55 cm | 2.25 cm |
| 8 | Variance | 0.07 cm ² | 0.07 cm ² | 0.06 cm ² | 0.05 cm ² |
| 16 | Number of values | 239 | 257 | 194 | 258 |
| 16 | Mean | 1.01 m | 0.99 m | 0.99 m | 1.0 m |
| 16 | Range | 3.46 cm | 4.04 cm | 13.2 cm | 3.44 cm |
| 16 | Standard Deviation | 1.60 cm | 1.95 cm | 2.17 cm | 1.51 cm |
| 16 | Variance | 0.03 cm ² | 0.03 cm ² | 0.05 cm ² | 0.02 cm ² |

Indoor - Lidars Comparison

Considering a static scene, the RS-LiDAR16, Quanergy M8, RPLIDAR A3 and the Sick 551 are positioning in front of a planar wall (**cardboard boxes**), at a distance of approximately **1.01 m and 1.90m with $\pm 0.01m$** .

For each environment, the lidar is launched after at least 2 minutes of non-use for 3 minutes. A 15 seconds bag is recorded for data post-process.



Lidars test parameters

| Parameters / Lidars | RS-LiDAR16 (3D) | Quanergy M8-1 (3D) | RPLIDAR A3 (2D) | Sick 551 (2D) |
|-----------------------|--------------------|--------------------|--------------------|--------------------|
| Scanning Frequency | 10Hz | 10Hz | 10Hz | 15Hz |
| Rotational speed | 600 rpm | 600 rpm | 600 rpm | 900 rpm |
| Horizontal resolution | 0.18° | ~ 0.06° | ~ 0.25° | 1° |
| Bag duration | 14.7 seconds | 14.7 seconds | 14.7 seconds | 14.7 seconds |
| Bag Samples | 148 scans | 148 scans | 174 scans | 221 scans |
| Points | NaN points removed | NaN points removed | NaN points removed | NaN points removed |

Lidars parameters table

RS-LiDAR16 - Distance 1.01 ± 0.01 m

Laser beam which measure the obstacle : 1, 2, 3, 4, 5, 6, 7, 8, 16, 15, 14, 13, 12, 11

| Parameters/Beam | 2 | 4 | 6 | 8 | 16 | 14 | 12 |
|-----------------|---------|---------|---------|---------|---------|---------|---------|
| Mean | 1.05 m | 1.03 m | 1.05 m | 1.05 m | 1.03 m | 1.03 m | 1.05 m |
| Range | 5.13 cm | 4.34 cm | 5.13 cm | 5.13 cm | 4.34 cm | 4.34 cm | 5.13 cm |
| Value number | 225 | 228 | 225 | 225 | 228 | 228 | 225 |

Quanergy - Distance 1.01 ± 0.01 m

Laser beam which measure the obstacle : 3, 4, 5, 6, 7, 8

| Parameters/Beam | 3 | 4 | 5 | 6 | 7 | 8 |
|-----------------|---------|---------|---------|---------|---------|---------|
| Mean | 1.01 m | 1.00 m | 1.03 m | 1.02 m | 1.01 m | 1.01 m |
| Range | 8.06 cm | 6.81 cm | 7.06 cm | 6.49 cm | 7.49 cm | 7.88 cm |
| Value number | 646 | 647 | 635 | 637 | 644 | 644 |

RPLIDAR A3 & Sick TIM551 - Distance 1.01 ± 0.01 m

| Lidars | RPLIDAR A3 | Sick TIM551 |
|-----------------|------------|-------------|
| Parameters/Beam | 1 | 1 |
| Mean | 1.01 m | 1.02 m |
| Range | 0.89 cm | 2.06 cm |
| Value number | 170 | 43 |

RS-LiDAR16 - Distance 1.90 ± 0.01 m

Laser beam which measure the obstacle : 4, 5, 6, 7, 8, 16, 15, 14, 13

| Parameters/Beam | 5 | 6 | 7 | 8 | 16 | 15 | 14 | 13 |
|-----------------|---------|---------|---------|---------|---------|---------|---------|---------|
| Mean | 1.92 m | 1.89 m | 1.89 m | 1.91 m | 1.90 m | 1.91 m | 1.92 m | 1.91 m |
| Range | 6.84 cm | 3.48 cm | 2.01 cm | 5.17 cm | 1.66 cm | 2.74 cm | 3.59 cm | 2.29 cm |
| Value number | 120 | 148 | 149 | 147 | 147 | 148 | 146 | 120 |

Quanergy - Distance 1.90 ± 0.01 m

Laser beam which measure the obstacle : 4, 5, 6, 7, 8

| Parameters/Beam | 4 | 5 | 6 | 7 | 8 |
|-----------------|---------|---------|---------|---------|---------|
| Mean | 1.92 m | 1.90 m | 1.91 m | 1.91 m | 1.91 m |
| Range | 4.76 cm | 4.64 cm | 4.42 cm | 4.55 cm | 5.09 cm |
| Value number | 352 | 352 | 352 | 352 | 352 |

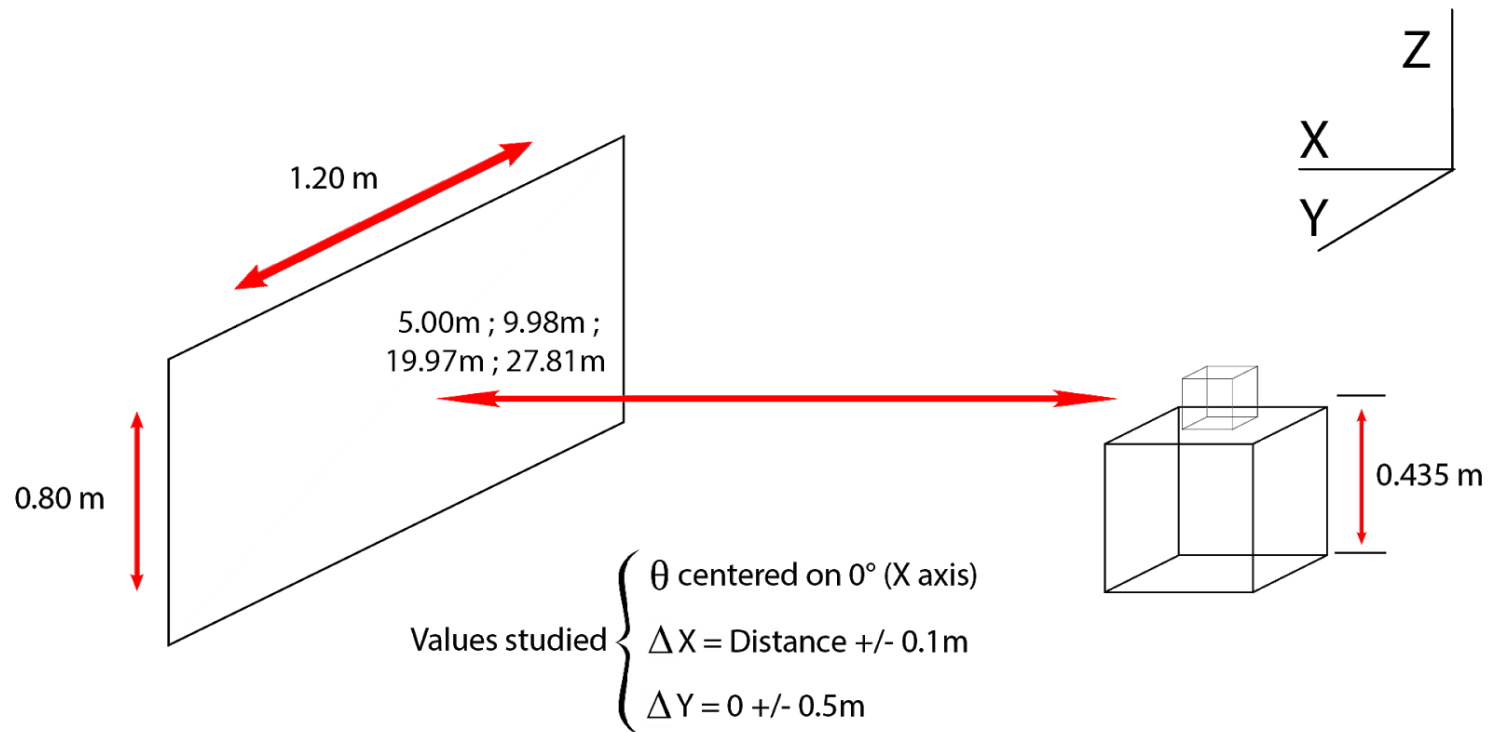
RPLIDAR A3 & Sick TIM551 - Distance 1.90 ± 0.01 m

| Lidars | RPLIDAR A3 | Sick TIM551 |
|-----------------|------------|-------------|
| Parameters/Beam | 1 | 1 |
| Mean | 1.90 m | 1.92 m |
| Range | 6.59 cm | 3.68 cm |
| Value number | 92 | 23 |

Outdoor - Lidars Comparison

Considering a static scene, the RS-LiDAR16 and Quanergy M8 are positioning in front of a planar wall (**condensed wood**), at a distance of approximately **5.00 m, 9.98m, 19.97m and 27.81m with $\pm 0.01m$** .

For each environment, the lidar is launched after at least 2 minutes of non-use for 3 minutes. A 30 seconds bag is recorded for data post-process.



Lidars test parameters

| Parameters / Lidars | RS-LiDAR16 (3D) | Quanergy M8-1 (3D) |
|-----------------------|-----------------------|------------------------------------|
| Scanning Frequency | 5 / 10 / 20 Hz | 5 / 10 / 20 / 30 Hz |
| Rotational speed | 300 / 600 / 1200 rpm | 300 / 600 / 1200 / 1800 rpm |
| Horizontal resolution | 0.09° / 0.18° / 0.36° | 0.03° / ~ 0.06° / ~ 0.12° / 0.2° |
| Bag duration | 29.57 seconds | 29.57 seconds |
| Bag Samples | 149 / 298 / 515 scans | 151 / 299 / 598 / Not Tested scans |
| Points | NaN points removed | NaN points removed |

Lidars parameters table

RS-LiDAR16 - Distance 5.00 ± 0.01 m

Laser beam which measure the obstacle : **7, 8, 15, 16**

| Beam | Parameters | 5Hz | 10Hz | 20Hz |
|------|------------|--------|--------|--------|
| 7 | Mean | 4.94 m | 4.94 m | 4.96 m |

| | | | | |
|----|--------------|---------|---------|---------|
| 7 | Range | 4.64 cm | 1.89 cm | 0.76 cm |
| 7 | Value number | 80 | 32 | 19 |
| 8 | Mean | 4.98 m | 4.98 m | 4.98 m |
| 8 | Range | 6.13 cm | 4.66 cm | 3.69 cm |
| 8 | Value number | 110 | 56 | 37 |
| 16 | Mean | 5.01 m | 5.01 m | 5.02 m |
| 16 | Range | 4.86 cm | 4.26 cm | 4.83 cm |
| 16 | Value number | 111 | 58 | 36 |
| 15 | Mean | 5.01 m | 5.01 m | 5.01 m |
| 15 | Range | 4.20 cm | 1.90 cm | 7.37 cm |
| 15 | Value number | 80 | 32 | 19 |

Quanergy - Distance 5.00 ± 0.01 m

Laser beam which measure the obstacle : **6, 7, 8**

| Beam | Parameters | 5Hz | 10Hz | 20Hz |
|------|------------|---------|---------|---------|
| 6 | Mean | 5.02 m | 5.03 m | 5.03 m |
| 6 | Range | 4.31 cm | 4.23 cm | 4.06 cm |

| | | | | |
|---|--------------|---------|---------|---------|
| 6 | Value number | 336 | 170 | 85 |
| 7 | Mean | 5.02 m | 5.02 m | 5.03 m |
| 7 | Range | 4.57 cm | 4.36 cm | 4.37 cm |
| 7 | Value number | 336 | 170 | 84 |
| 8 | Mean | 5.02 m | 5.02 m | 5.02 m |
| 8 | Range | 4.40 cm | 4.18 cm | 3.88 cm |
| 8 | Value number | 336 | 170 | 84 |

RS-LiDAR16 - Distance 9.98 ± 0.01 m

Laser beam which measure the obstacle : **8, 16**

| Beam | Parameters | 10Hz | 20Hz |
|------|--------------|---------|---------|
| 8 | Mean | 10.01 m | 10.03 m |
| 8 | Range | 0.97 cm | 1.51 cm |
| 8 | Value number | 15 | 8 |
| 16 | Mean | 10.01 m | 10.02 m |
| 16 | Range | 0.67 cm | 5.47 cm |
| 16 | Value number | 16 | 8 |

Quanergy - Distance 9.98 ± 0.01 m

Laser beam which measure the obstacle : 7

| Beam | Parameters | 10Hz | 20Hz |
|------|--------------|--------|--------|
| 7 | Mean | 9.99 m | 9.99 m |
| 7 | Range | 2.5 cm | 2.6 cm |
| 7 | Value number | 43 | 38 |

RS-LiDAR16 - Distance 19.97 ± 0.01 m

Laser beam which measure the obstacle : 16

| Beam | Parameters | 10Hz | 20Hz |
|------|--------------|---------|---------|
| 16 | Mean | 20.02 m | 20.00 m |
| 16 | Range | 0.57 cm | 5.1 cm |
| 16 | Value number | 8 | 3 |

Quanergy - Distance 19.97 ± 0.01 m

Laser beam which measure the obstacle : 7

| Beam | Parameters | 10Hz | 20Hz |
|------|--------------|---------|---------|
| 7 | Mean | 20.00 m | 20.00 m |
| 7 | Range | 2.61 cm | 2.42 cm |
| 7 | Value number | 41 | 18 |

RS-LiDAR16 - Distance 27.81 ± 0.01 m

Laser beam which measure the obstacle : **16**

| Beam | Parameters | 10Hz | 20Hz |
|------|--------------|---------|----------|
| 16 | Mean | 27.82 m | No value |
| 16 | Range | 1.0 cm | No value |
| 16 | Value number | 6 | No value |

Quanergy - Distance 27.81 ± 0.01 m

Laser beam which measure the obstacle : **7**

| Beam | Parameters | 10Hz | 20Hz |
|------|------------|---------|---------|
| 7 | Mean | 27.84 m | 27.83 m |

| | | | |
|---|--------------|--------|---------|
| 7 | Range | 1.0 cm | 2.80 cm |
| 7 | Value number | 30 | 14 |