Microsoft KinectV1

Overview

Cameramode: filter off

Frames / Measurement: 100

Size: 640 px x 480 px

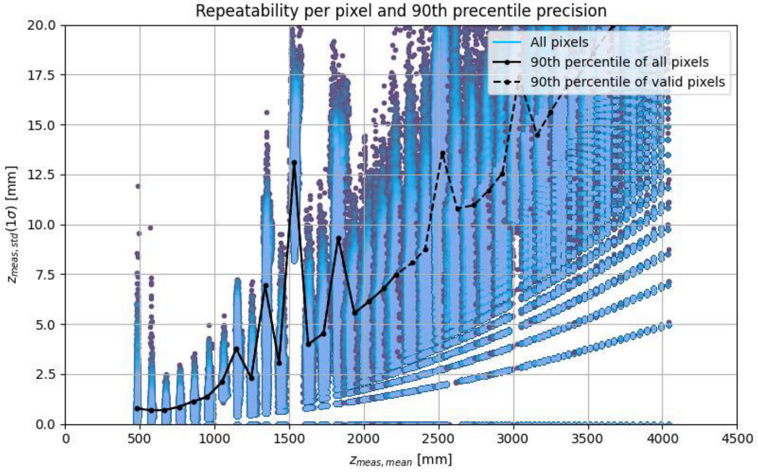
Measurement range (324 mm ... 4034 mm):

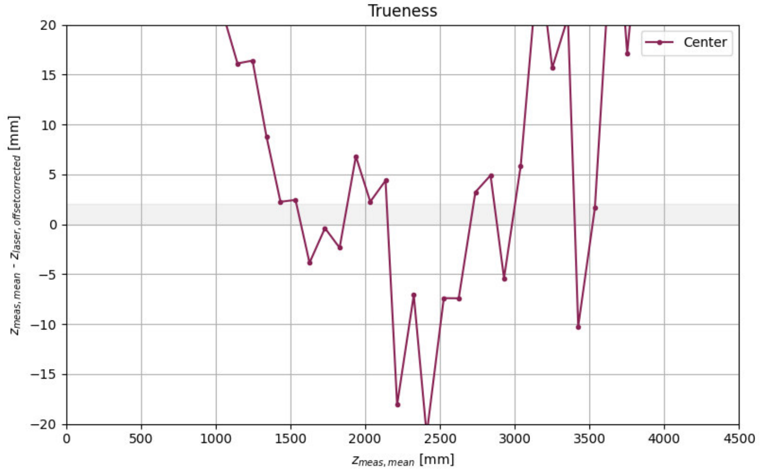
Repeatability (center):	< 35.5 mm
Trueness (center):	< 59.4 mm
Accuracy (center):	< 104.2 mm

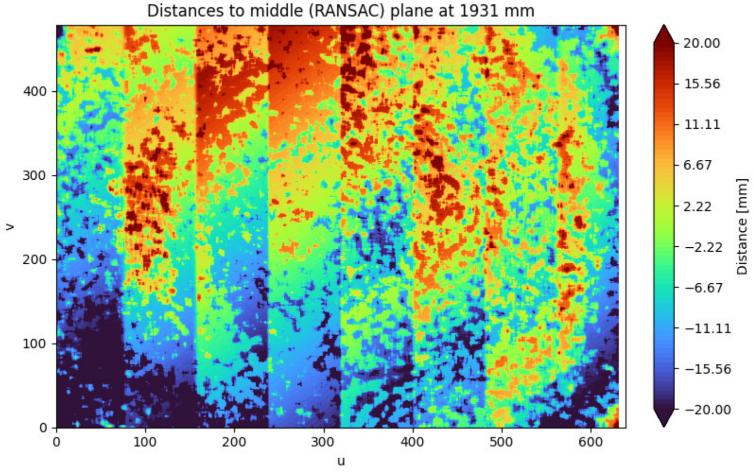
Reference value (1931 mm):

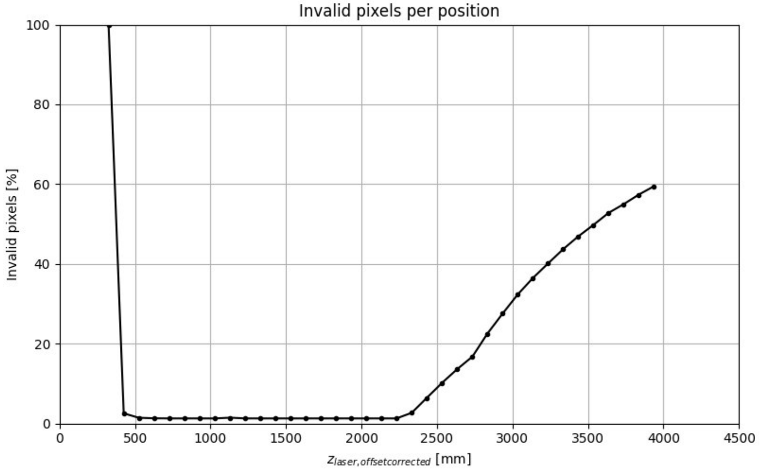
Precision (Q90% valid):	5.5 mm
RMS height (primary):	12.0 mm

Comment: /

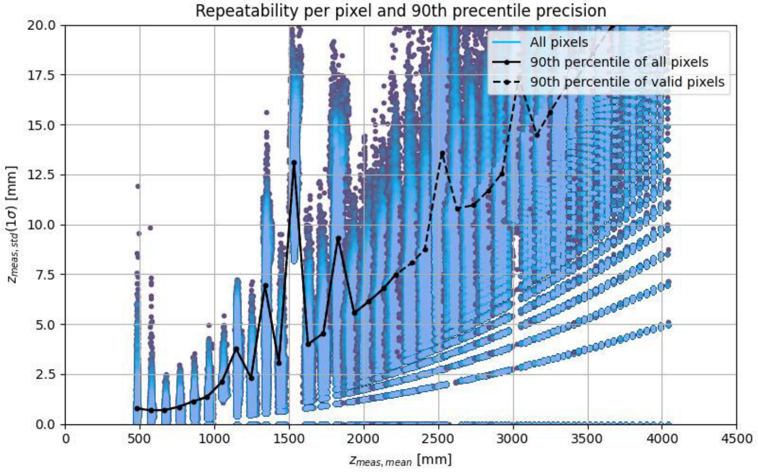


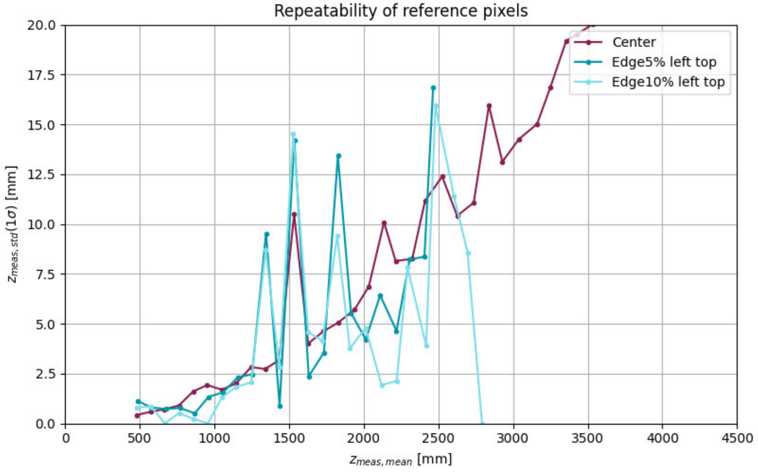


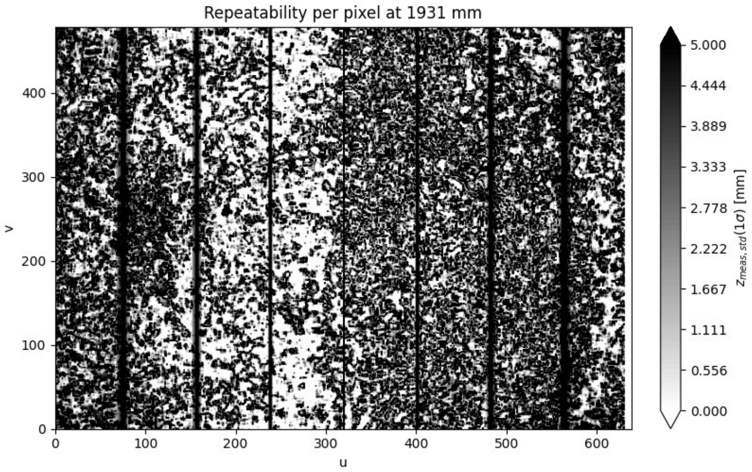


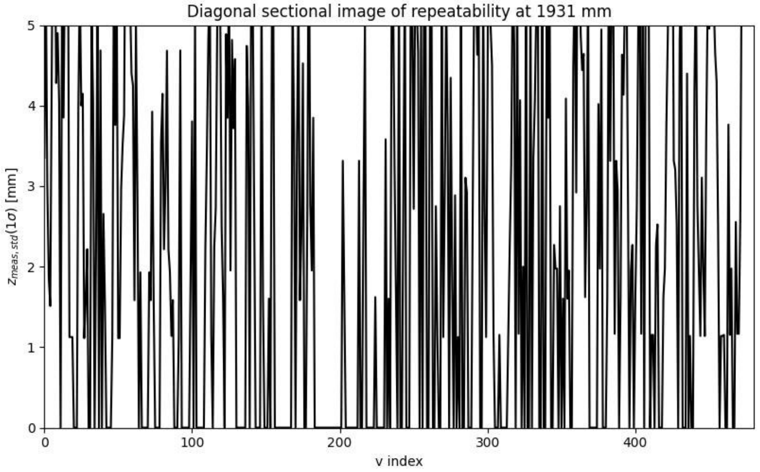


Repeatability and Precision









Precision: Closeness of agreement between individual test results. Usually given in form of uncertainty as the standard deviation. (ISO 5725-1:1994)

If obtained under repeatable conditions - with the same methods and equipment, in the same location and within a short time frame - the precision is called **repeatability**. Here this refers to the standard deviation of a specific pixel at a fixed distance. If the standard deviation of more than one location is evaluated, e.g. multiple pixels or mutliple distances, it is called **precision.**

Repeatability (1931 mm):

center:	+5.7 mm

Precision (1931 mm):

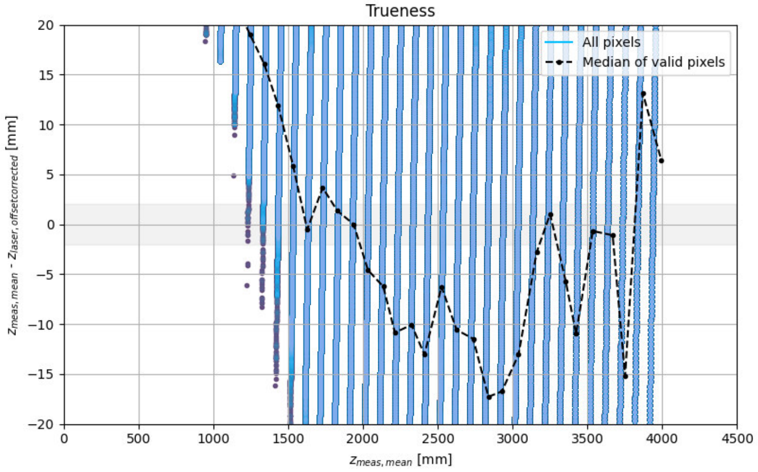
90th percentile all:	+5.6 mm
90th percentile valid:	+5.5 mm

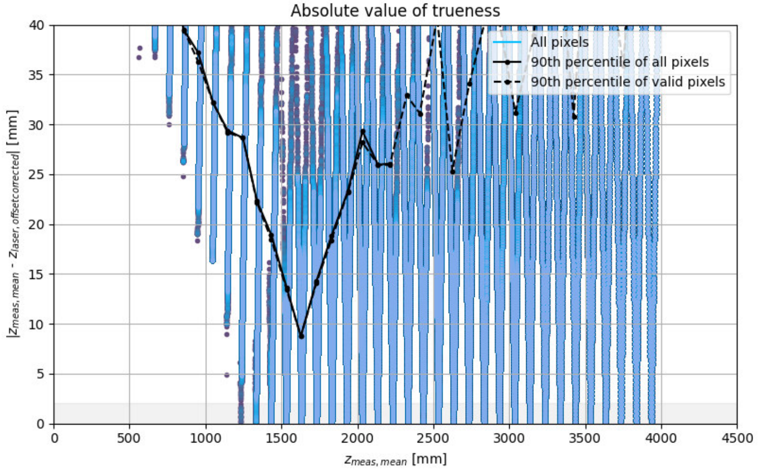
Precision (324 mm ... 4034 mm):

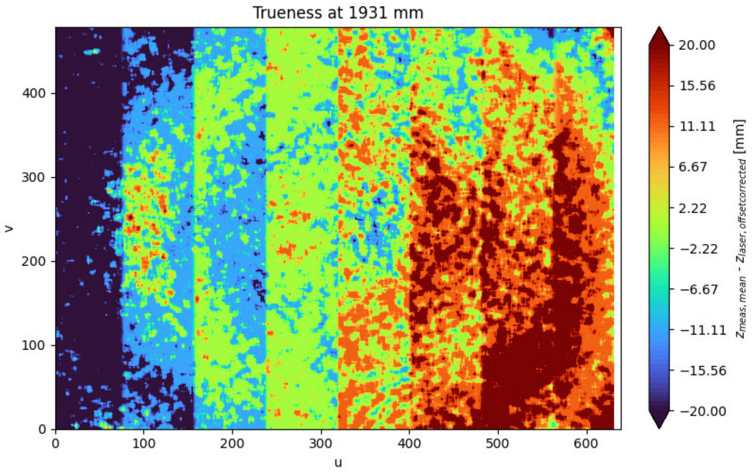
Last valid 90th percentile:	+7.5 mm (2231 mm)

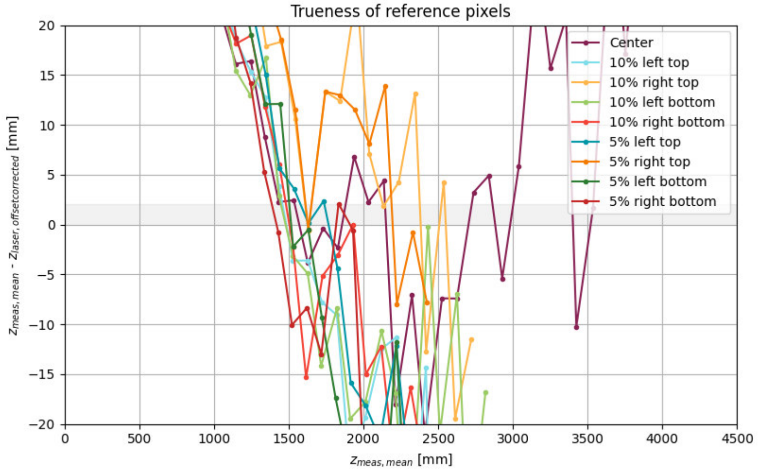
Microsoft KinectV1 | Measurement error z

Trueness









Trueness: Closeness between average of a large series of test results and its accepted reference value (ISO 5725-1:1994). Here the difference between the average of 100 frames and the laser distance sensor's measured value is determined.

Trueness (324 mm ... 4034 mm):

Center:	-21.1 mm ... +59.4 mm
Median of valid:	-17.3 mm ... +436.8 mm
Last valid 90th percentile:	+26.1 mm at 2231 mm

Trueness (1931 mm):

90th percentile all:	+23.3 mm
90th percentile valid:	+23.2 mm

Accuracy

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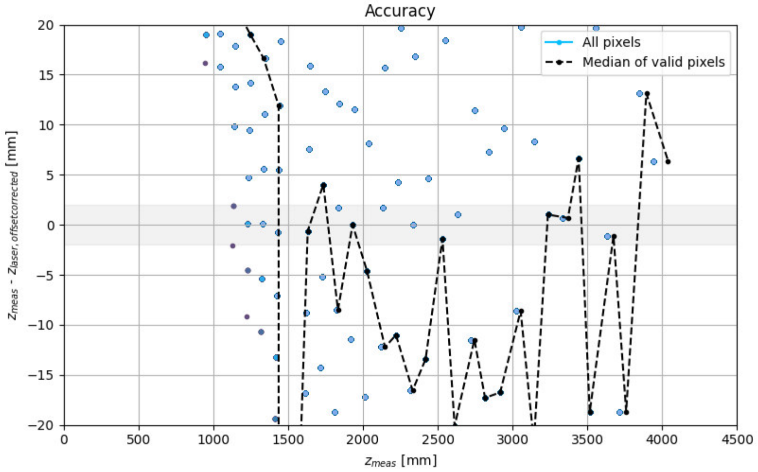

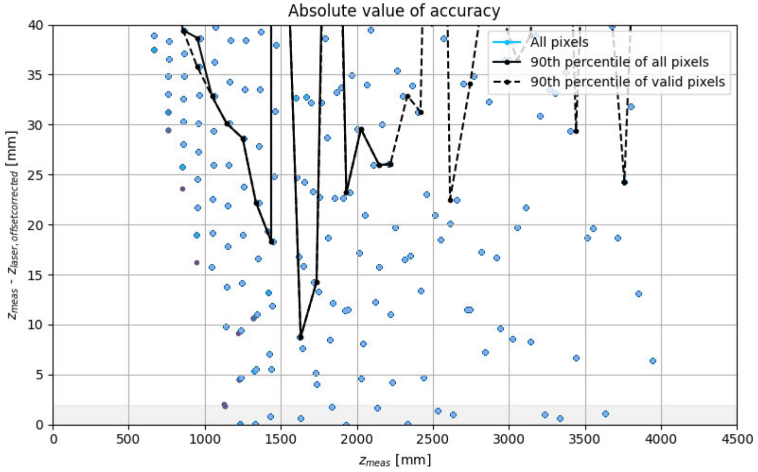

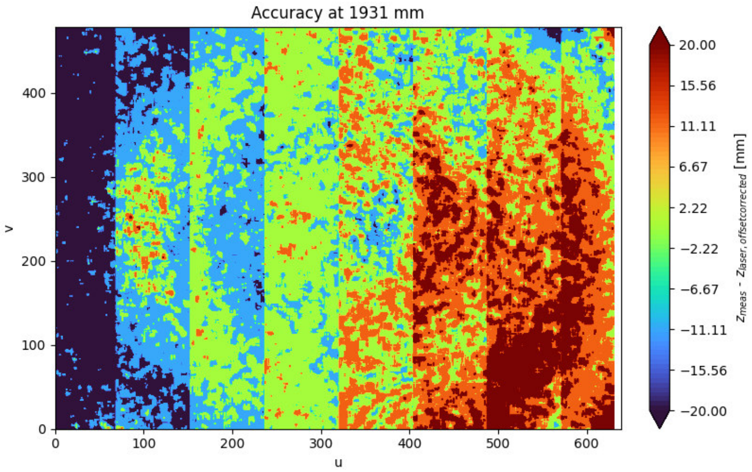

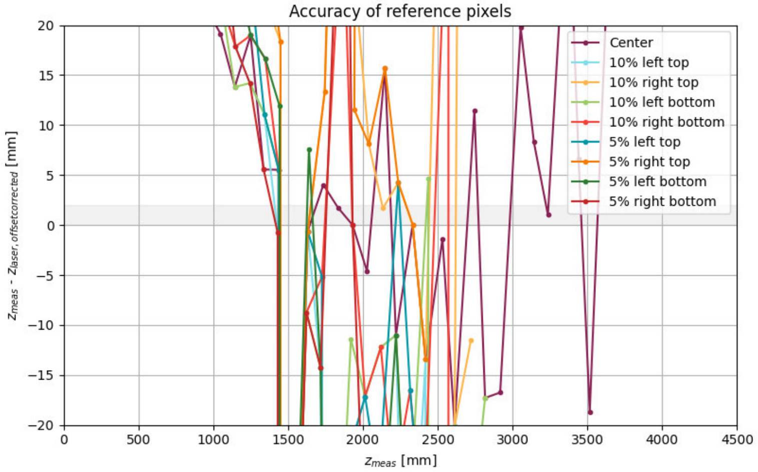

Accuracy: Closeness between a single test results and its accepted reference value (ISO 5725-1:1994). Here the difference between each pixel's distance value and the laser distance sensor's measured value is used. In contrast to the trueness, the pixel's values are not averaged. Due to this the accuracy represents a combination of systematic and statistic errors.

Accuracy (324 mm ... 4034 mm):

Center:	-95.1 ... +104.2 mm
Median of valid:	-88.7 ... +55.7 mm
Last valid 90th percentile:	26.1 mm at 2231 mm

Accuracy (1931 mm):

90th percentile all:	+23.2 mm
90th percentile valid:	+23.2 mm

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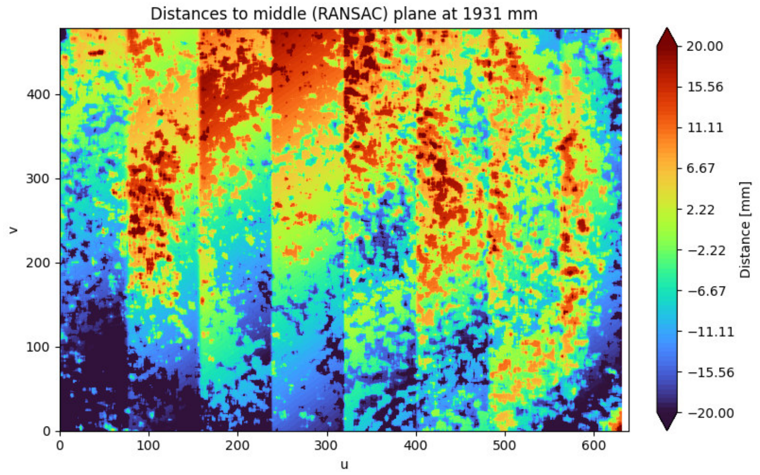
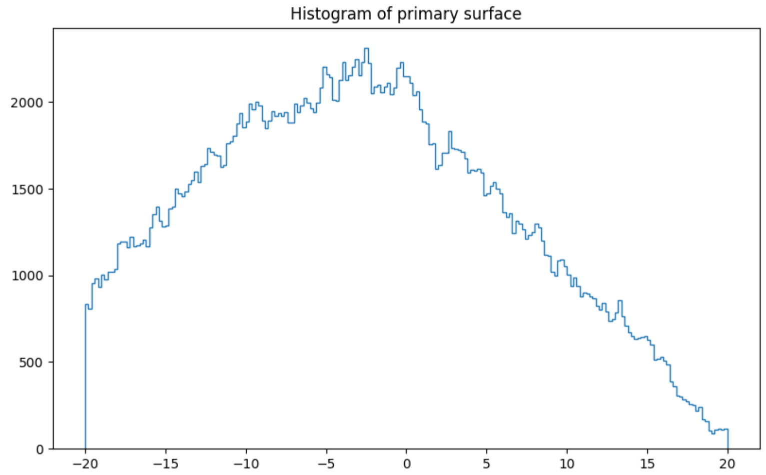
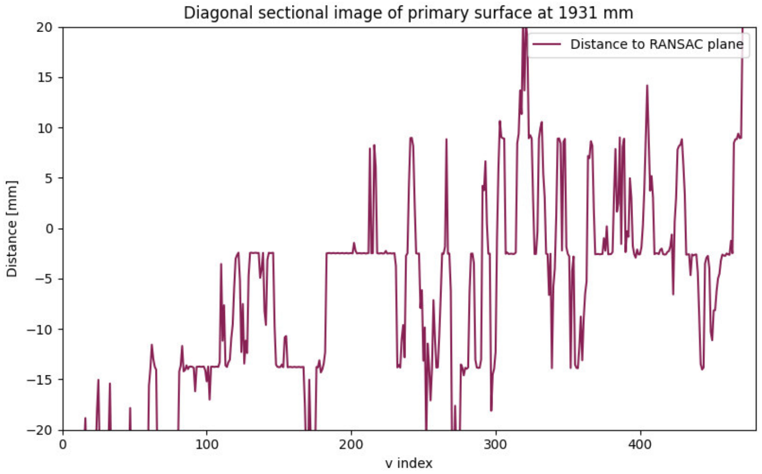
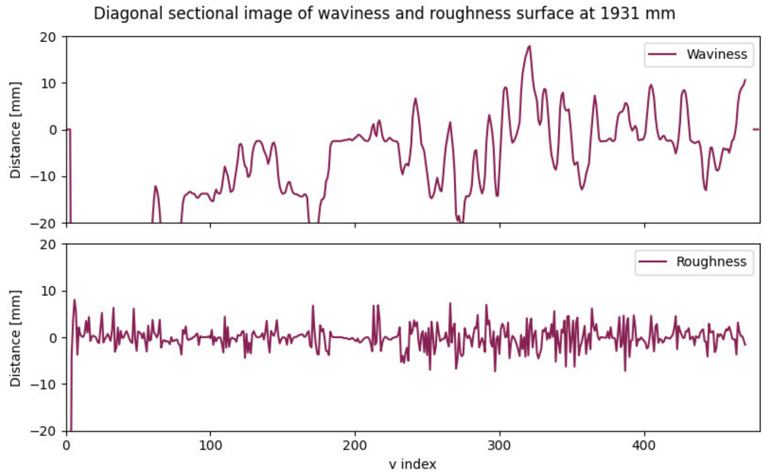
Surface texture









Primary surface: Surface after removing the form surface. Here a plane derived with the RANSAC algorithm. (ISO 21920-2:2021)

Waviness surface: Primary surface without small-scale components (Binomial-filter, 8th order) (ISO 21920-2:2021).

Roughness surface: Primary surface without large-scale components (ISO 21920-2:2021). Here the waviness surface substracted from the primary surface.

Root mean square height (1931 mm):

Primary surface:	12.0 mm
Waviness:	11.1 mm
Roughness:	3.6 mm

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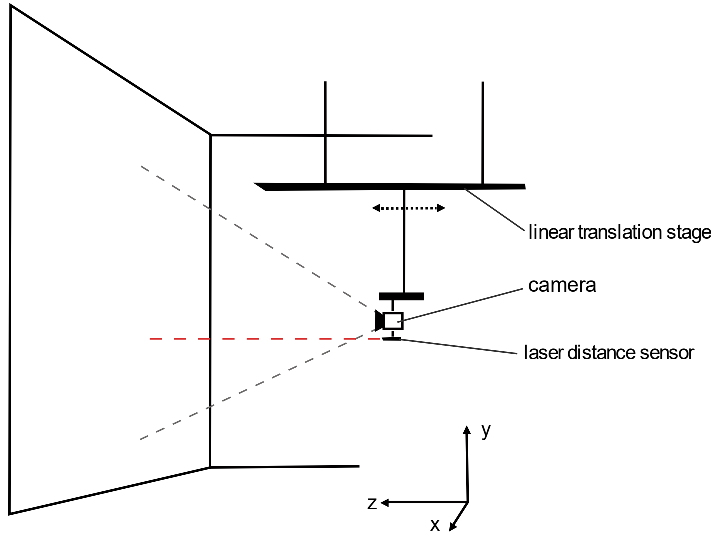
Appendix

Measurement setup:



Equipment:

Laser distance sensor:

Type:	Dimetix DAE-10-050
Precision:	1 mm (2 σ)
Repeatability:	0,3 mm

Linear translation unit:

Offset to wall:	377 mm
Movement (0.37 to 4m):	0.05° horizontal / 0.18° vertical
Range:	0 – 4 m

Laboratory:

Planarity of wall:	± 1.5 mm
Accuracy of ground truth:	< 4.3 mm

Integration sphere:

Type:	Newport 819D-SL-2-CAL2
Spectral Range:	400 - 1100 nm
Calibration Uncertainty:	± 2,5% @ < 1000 nm / ± 3% @ > 1000 nm

Oscilloscope:

Type:	Tektronix MSO64
Bandwidth:	4 GHz
Probe:	iCHaus iC212NST
Probe bandwidth:	1.4 GHz
Probe spectral range:	320 – 1000 nm

Camera:

Type:	KinectV1
Distributor:	Microsoft
Total:	307200 px
Effective:	303360 px (98.7%)

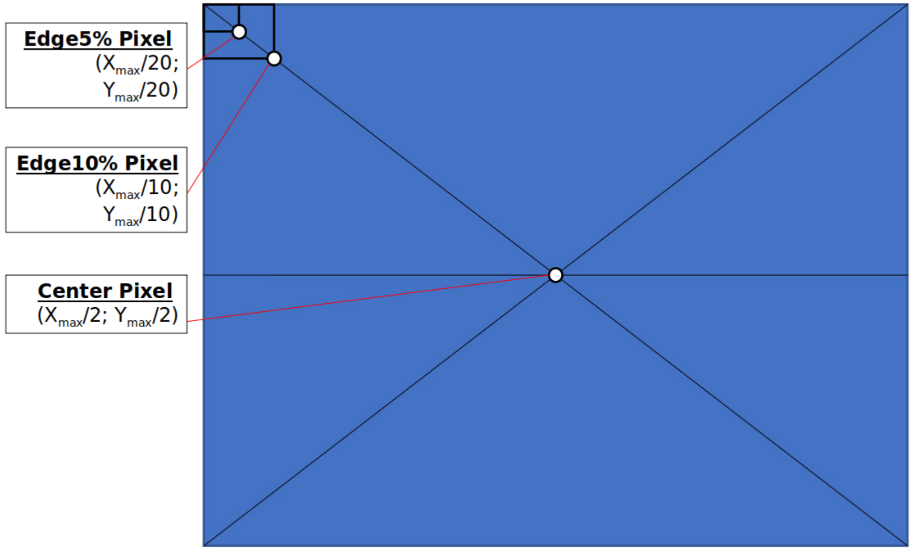
Appendix

Utilized distances:

Single measurement: z_{meas}
Arithmetic mean value: $z_{meas,mean}$
Median value: $z_{meas, median}$
Standard deviation: $z_{meas,std}$

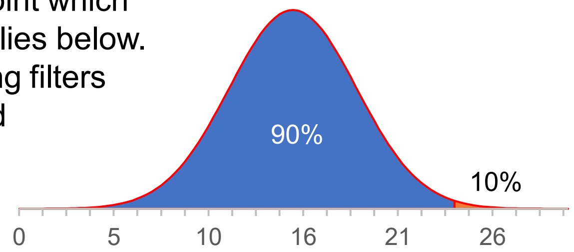
Performance reference pixels:

Representative pixels are used to reduce the amount of evaluated data.
The center pixel represents the frame's middle part. As the noise increases with the distance, it is expected that edge pixels show the highest noise levels. Those noise levels can be determined by using the edge 5% or the edge 10% pixel.



90th percentile:

The 90th percentile is a statistical cut point which marks the value where 90% of the data lies below.
In most cameras internal post-processing filters set bad pixels to invalid. As these invalid pixels do no longer represent a specific number, the quantile cannot be calculated. To be able to calculate the quantile again, those invalid pixels can be replaced with a value higher than all remaining pixels.
However, if the pixels were invalidated by the metrics script as a consequence of the measurement set-up, e.g. pixel lying on the curtains, this work around should not be applied as the original pixels may have been better than the remaining valid pixels. For this case, we calculate the 90th percentile of the remaining valid pixels.



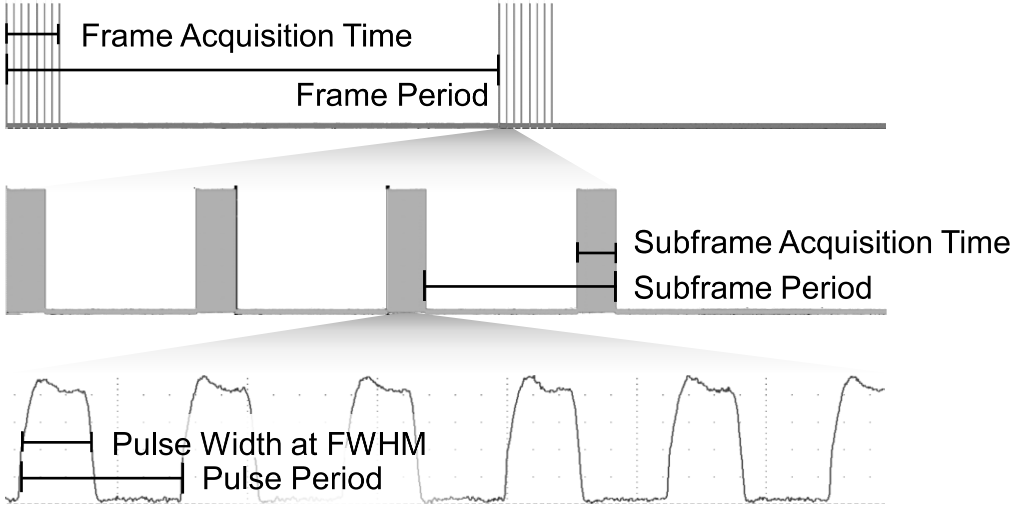
RANSAC algorithm:

Given that a point cloud represents a noisy geometrical shape of a known type, the random sample consensus (RANSAC) algorithm finds the parameters of the best fitting shape for this data set. The algorithm finds the parameters of the shape with the highest number of inlying points. As most points will not exactly lie within the shape, a threshold is defined: If a point lies within smaller than threshold distance, the point is accepted as an inlier. The RANSAC algorithm can be used for every shape that can be coded by a set of parameters.

Appendix

Optical measurement:

Definitions:



Equations:

Frame Energy: $E_{Frame} = \sum E_{Subframe}$

Subframe energy: $E_{Subframe} = \int P_{meas}$

Pulse energy: $E_{Pulse} = \frac{E_{Subframe}}{N_{Pulse}}$

Subframe dutycycle: $DC_{subframe} = \frac{\text{Subframe Acquisition Time}}{\text{Subframe Period}}$

Energy-Density-Weighted Depth Precision Index (EPI)

is a derived metric that relates the depth precision of a 3D system to the optical energy per measurement and the illuminated area. EPI offers a fair and consistent benchmark for evaluating and comparing the efficiency and performance of 3D measurement systems across diverse designs and configurations.

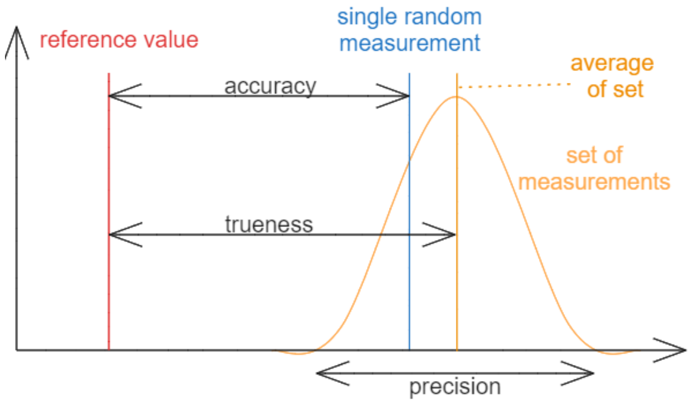
Calculation:
The EPI is the product of the precision index (Slide 2: Precision 2000m 90th percentile valid) times Optical Energy (Slide 7: Opt. energy per Frame), divided by measured area.

$$EPI = \frac{PP90_{2m} \cdot Q_F}{A_{FoV}}$$

Interpretation Guide:
A low EPI (unit: mm*Ws/m^2) indicates high efficiency, while a high EPI reflects lower efficiency. High measured distance noise or high optical energy used per measurement result in a high EPI. In contrast, a large field of view (FoV) reduces the EPI.

Appendix

Measurement error:



For describing the statistical measurement errors, precision and repeatability are used. Both parameters are defined by the closeness of agreement between individual test results, that are obtained independently under the same conditions. Precision is usually given in the form of imprecision and is calculated as the standard deviation. To obtain independent results, the measurement is not to be influenced by any previous results and must be reproducible. If the precision is obtained under repeatable conditions, hence with the same methods and equipment in the same location within a short time frame, it is called repeatability. Just like with precision, repeatability is usually given in the form of imprecision. In a single measurement random and systematic errors superpose each other and cannot be seen individually. To examine the performance of a single measurement, accuracy is used. This parameter describes how close a single test result is to its accepted reference value (cf. ISO 5725-2:1994).

Measurement procedure:

The camera is attached under the linear translation stage opposite a white wall, which serves as the measurement target. The stage moves the camera from a distance of 324 mm to 4034 mm. Over the measurement range, the stages stops every 100 mm (here 97 mm) to let the camera capture 100 frames, which are then averaged. Additionally, a laser distance sensor accompanies the camera and measures the distance between translation stage and target.

Accuracy: The accuracy is given as the difference between the laser distance sensor and a specific pixel's measurement of an unaveraged frame. The frame is chosen randomly.

Trueness: The trueness is calculated with the averaged data as the difference between the laser distance sensor and a specific pixel's measurement of an averaged frame.

Precision / Repeatability: For Precision and repeatability the standard deviation of all 100 frames taken at a certain position is determined. While the repeatability describes the deviation of a single pixel within a frame, the precision describes the deviation of multiple pixels or at multiple positions.

Surface texture: For primary, roughness and waviness surface, a plane is fitted through the data with the RANSAC algorithm. The primary surface is then given as the deviation or distance between a data point and the plane. For the waviness a lowpass filter is applied on the primary surface, for the roughness surface the waviness surface is subtracted from the primary surface.

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Imprint

Version: 1.3

Metric generated by Bastian Stahl.

Measurement taken by Bastian Stahl on 2025-02-05.

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https://www.h-brs.de/en/isf

https://doi.org/10.18418/opus-8898