

# BlackBox Analyzer

## Measuring grid accuracy

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## Introduction

Anchor Lab's BlackBox Analyzer software includes a digital measuring grid that allows users to perform real-world distance measurements directly within video imagery.

The measuring grid is based on close-range photogrammetric principles. By identifying the four corner points of a planar reference surface of known dimensions, the software estimates the geometric relationship between image coordinates and real-world coordinates. This allows distances within the defined plane to be measured directly from the image, despite perspective distortion caused by camera position and viewing angle.

In addition to perspective distortion, camera lenses may introduce radial distortion. Radial distortion is often the dominant lens-related geometric error and can cause otherwise straight features in object space to appear curved in the image. Accurate estimation of this distortion component would therefore improve the accuracy of photogrammetric measurements.

BlackBox Analyzer uses the known geometry of the reference surface to estimate the radial distortion. Since the reference rectangle is known to consist of straight sides with opposite sides remaining parallel (rectilinear) in object space, deviations from this geometry observed in the image can be attributed primarily to lens distortion. BlackBox Analyzer therefore allows the user to interactively adjust the dominant radial distortion parameter while observing the projected grid. The distortion parameter is accepted when the projected grid lines align with known straight features in the scene, such as conveyor belt edges, deck structures, or table boundaries.

This procedure provides a practical estimation of the most significant radial lens distortion component, which improves measurement accuracy, where radial lens distortion is present.

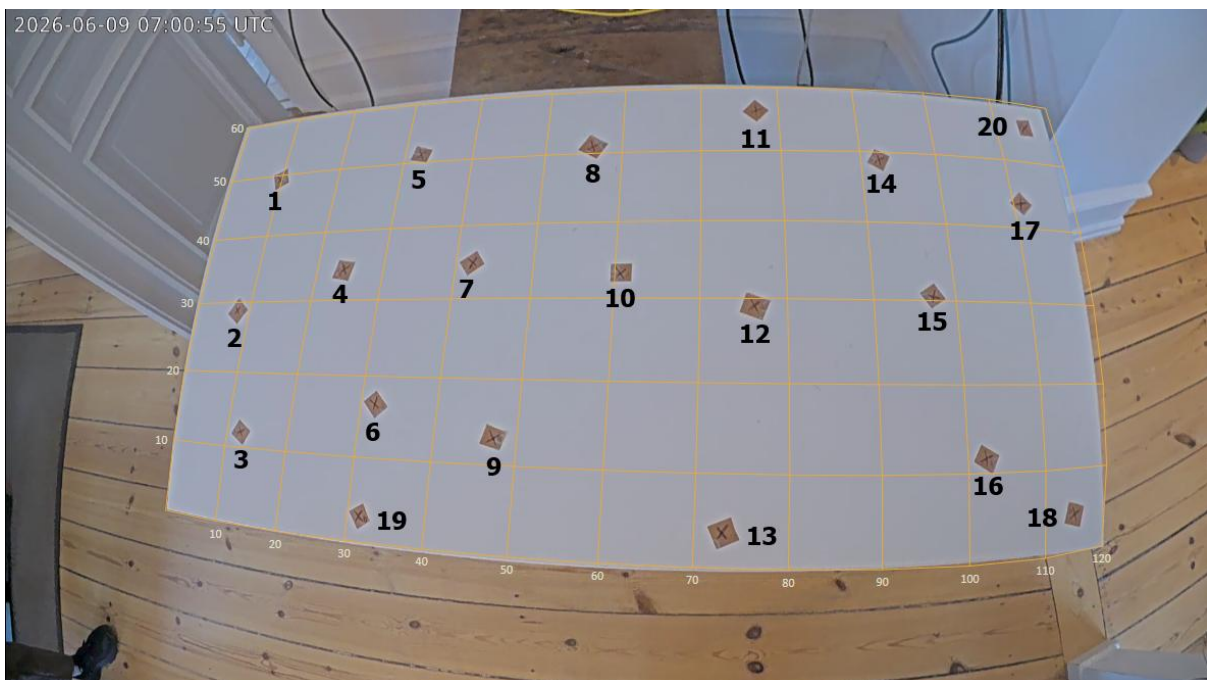
The following sections presents a practical validation of the measurement accuracy achieved by the BlackBox Analyzer digital measuring grid under representative operating conditions.

## Test setup

The software used is Anchor Lab's BlackBox Analyzer. A 2-megapixel IP dome camera with a 1/2.8" CMOS image sensor and a resolution of 1920 x 1080 pixels was used for the tests.

The camera view was representative of a typical electronic monitoring (EM) installation, including an oblique viewing angle and visible perspective distortion (see image below).

Twenty markers were placed at random locations on the table with each mark having a unique number. Distances between randomly selected pairs of markers were measured manually and compared against distances reported by the software.



Measurement surface: approximately 120 cm × 60 cm table.

The digital measuring grid was defined in the software by:

- 1) Placing the four corner points on the table corners.
- 2) Entering the known physical width and height of the table in cm.
- 3) Performing a visual estimation of the radial distortion. This is visualized in the image above as the curved grid borders, following the table boundary.

No additional points were used during the calibration stage.

## Detailed measurement results

Twenty independent and randomly chosen distance measurements were performed. For each measurement, the true distance was measured manually and compared with the distance reported by the BlackBox Analyzer digital measuring grid.

The measurement error was calculated as:

$$\text{Error} = \text{Software Distance} - \text{True Distance}$$

Positive values indicate that the software overestimated the distance, while negative values indicate an underestimation. Below is a table showing the marker numbers, the real distance, the measured distance and the error.

#	Marker 1	Marker 2	True distance (cm)	Software distance (cm)	Error (cm)
1	1	5	23	22,6	-0,4
2	7	13	42,5	42,9	0,4
3	3	14	88,1	87,4	-0,7
4	11	13	51,8	52	0,2
5	16	18	14,3	14,3	0
6	7	10	17,9	18,2	0,3
7	6	19	13,4	13,4	0
8	11	14	16,9	16,8	-0,1
9	4	20	93,3	92,7	-0,6
10	8	16	60,2	59,7	-0,5
11	4	9	30,6	31	0,4
12	2	3	17,2	17,3	0,1
13	17	20	12,9	12,8	-0,1
14	7	12	33,6	34	0,4
15	4	5	18,4	18,7	0,3
16	1	9	51,5	51,8	0,3
17	13	18	42,1	41,5	-0,6
18	12	19	51,2	51,2	0
19	16	19	71,4	70,5	-0,9
20	4	11	56,4	56,8	0,4

## Results

The following accuracy metric were calculated from the measurement results.

- **Bias** indicates whether the software systematically over- or underestimates measurements.
- **Mean Absolute Error (MAE)** represents the average measurement deviation.
- **Root Mean Square Error (RMSE)** is the standard accuracy metric used in measurement and photogrammetry applications and represents the typical measurement error.
- **Maximum Error** is the largest deviation observed during testing.
- **Mean Relative Error (%)** represents the average measurement deviation expressed as a percentage of the true distance, allowing accuracy to be compared across measurements of different lengths.

Below the calculated results are listed.

METRIC	RESULT
NUMBER OF MEASUREMENTS	20
BIAS	+0.055 cm
MEAN ABSOLUTE ERROR (MAE)	0.335 cm
RMSE	0.413 cm
MAXIMUM ABSOLUTE ERROR	0.9 cm
MEAN RELATIVE ERROR	0.85 %

The RMSE of 0.413 cm (4.1 mm) indicates a typical measurement error of approximately 4.1 mm under the tested conditions.

The largest observed deviation was 0.9 cm.

The validation data do not indicate any significant systematic measurement bias (+0.055 cm). The observed errors remained low for all measurements, yielding an overall RMSE of 0.41 cm and a mean relative error of 0.85%.

The remaining measurement deviations are primarily attributed to residual lens distortion. While the dominant radial distortion component is estimated and compensated for during grid creation, higher-order distortion terms are left at their default values. Consequently, small geometric deviations may remain within the image and can typically become more noticeable over longer measurement distances.

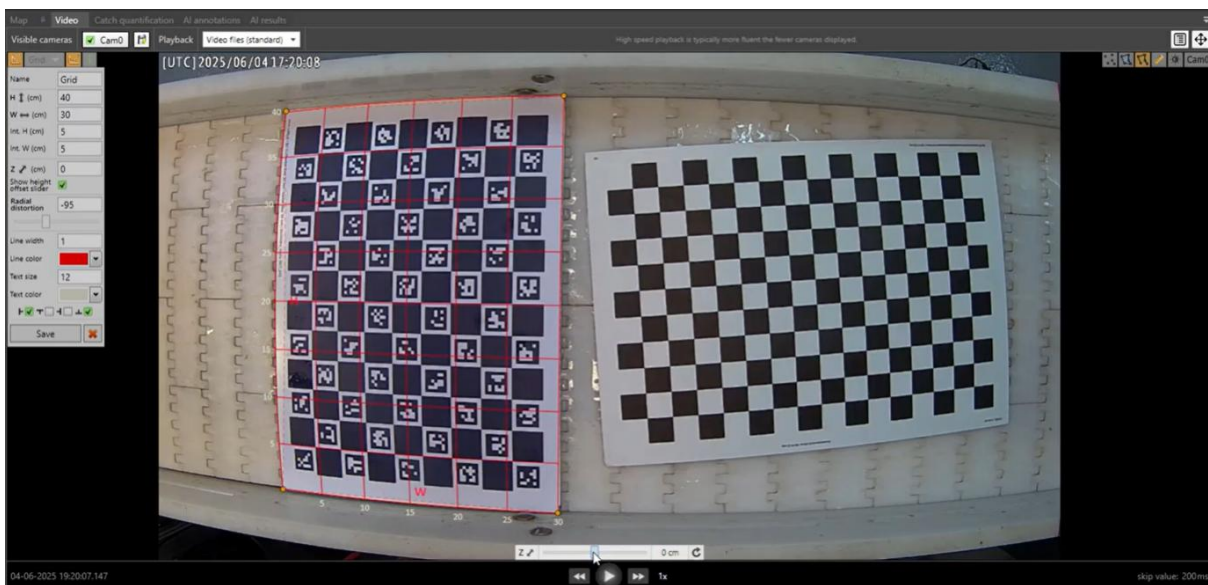
## Practical demonstration using calibration targets

In addition to the validation measurements described above, Anchor Lab has performed practical demonstrations using calibration targets of known dimensions.

The demonstration shown in the following video illustrates the creation of a digital measuring grid using Anchor Lab's BlackBox Analyzer software and the usage of it:

<https://youtu.be/4INQTWclQp0>

A frame from the video demonstrating the setup is visualized below.



The demonstration uses calibration targets with accurately known dimensions, including:

CALIBRATION TARGET	SPECIFICATION
<b>APRILTAG GRID</b>	6×6 markers, marker size 43.86 mm, separation 13.17 mm
<b>CLASSIC CHESSBOARD</b>	15×10 squares, square size 23.80 mm

After the measuring grid is established, the software is used to measure individual squares within the calibration targets.

Measurements were performed both:

- within the area bounded by the measuring grid, and
- outside the grid boundaries.

In both cases, the measured dimensions differed only marginally from the known physical dimensions of the calibration targets. For example, a calibration square with a known size of 23.8 mm was measured outside the grid boundary as approximately 24.0 mm, corresponding to an error of approximately 0.2 mm (0.84%).

This demonstrates that useful measurements can often be performed outside the immediate area used for grid definition. However, measurement accuracy is generally expected to decrease (in some cases rapidly) as the measurement location moves further from the area used to establish the photogrammetric model. Consequently, it is recommended that the calibrated grid area covers the full measuring area for the most accurate results, with measurements outside the grid used only where necessary.

While this demonstration is intended as a practical illustration rather than a formal accuracy assessment, it provides additional confidence that the photogrammetry-based measuring grid produces consistent measurements, in the same plane as where the grid is defined.

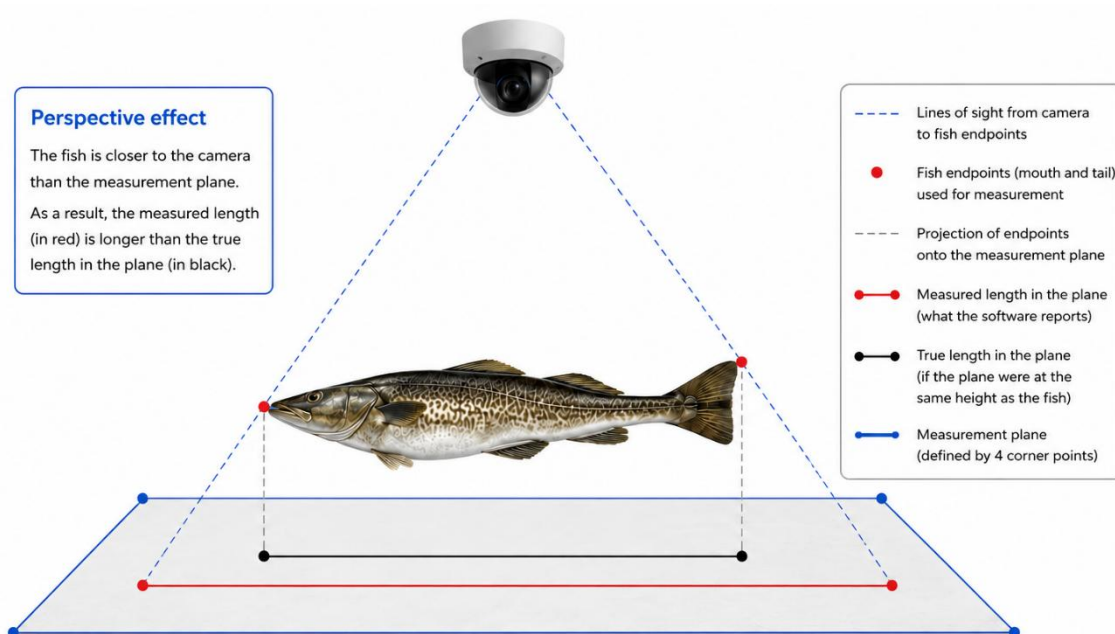
## Measurement considerations and limitations

The validation presented in this document was performed on a planar surface where both the calibration reference points and the measured targets were located within the same physical plane.

As with all photogrammetric measurement systems, the achievable accuracy depends on several factors, including:

- Accurate placement of the four reference corner points.
- Accurate entry of the physical dimensions used during grid creation.
- Image quality, camera resolution, and visibility of reference points.
- The measured object being located in the same plane used for calibration.

Measurements of objects positioned above or below the calibrated plane may exhibit additional error. For example, in fisheries applications, fish resting on top of other fish or elevated above the deck surface may not lie within the calibrated measurement plane (see image below).



To address this, BlackBox Analyzer provides a height adjustment feature that allows the measurement plane to be moved upwards or downwards relative to the original calibration plane. This enables the user to align the photogrammetric model more closely with the actual height of the object being measured and thereby reduce height-related measurement errors.

For this reason, the accuracy figures presented in this report should be considered representative of measurements performed within the calibrated plane, or where appropriate height compensation has been applied, under conditions similar to those used during validation.

## Conclusion

Anchor Lab's validation testing of the BlackBox Analyzer digital measuring grid demonstrated a mean absolute error of 0.335 cm, an RMSE of 0.413 cm (4.1 mm), and a mean relative error of 0.85% across 20 independent measurements. No significant systematic measurement bias was observed (mean bias +0.055 cm), indicating that the software does not consistently overestimate or underestimate measured distances.

The validation was performed using an oblique camera view representative of a typical electronic monitoring installation. It demonstrated that accurate measurements can be achieved using only four reference points, the known dimensions of the measurement plane, and visual adjustment of the dominant radial distortion parameter within Anchor Lab's measuring grid tool.

## Theoretical Measurement Range

The validation presented in this report demonstrates the accuracy achieved by the BlackBox Analyzer measuring grid under representative operating conditions. The following simplified photogrammetric model can be used to estimate the maximum camera-to-object distance at which measurement accuracy comparable to the validated RMSE may be expected. Beyond this distance, the expected measurement error resulting from image measurement precision may begin to exceed the validated grid accuracy.

### Formula

The relationship between object-space measurement accuracy, camera focal length, and sensor pixel size can be expressed as:

$$d = (1 \times C \times \text{RMSE}) / p$$

where:

d = maximum camera-to-object distance (mm)

C = focal length (mm)

RMSE = desired object-space measurement accuracy (mm)

p = pixel size (mm)

The constant, 1, corresponds to a practical assumption that the projected size of a single image pixel in the measurement plane should not exceed the validated RMSE. In other words, at the calculated camera distance, one pixel in the measurement plane corresponds approximately to the same physical distance as the validated measurement error.

This criterion is intentionally more conservative than the commonly used photogrammetric  $p/3$  image measurement precision assumption. While that assumption may be appropriate for estimating the theoretical limits of image measurement accuracy, the criterion used here is intended to provide a practical guideline for camera placement in electronic monitoring applications, where image detail and object visibility are also important considerations.

### Determining Pixel Size

The pixel size can be calculated from the physical sensor dimensions and image resolution.

$$p = \text{Sensor Width} / \text{Image Width} \quad \text{or} \quad p = \text{Sensor Height} / \text{Image Height}$$

where:

p = pixel size (mm)

Sensor Width = physical sensor width (mm)

Image Width = image width (pixels)

For example, if a camera uses a 1/2.8" CMOS image sensor with an active sensor width of approximately 6.46 mm and an image width of 2560 pixels, the pixel size is calculated as:

$$p = 6.46 / 2560$$

$p \approx 0.00252 \text{ mm}$

The same result can be obtained using the sensor height and image height.

**Example: Vivotek FD9383-HTV**

The Vivotek FD9383-HTV camera has the following relevant specifications:

- Sensor size: 1/2.8" CMOS (~6,46 mm x 4.84 mm).
- Resolution: 2560 × 1920 pixels (5MP).
- Approximate pixel size: 0.00252 mm (2.52 μm).
- Focal length: 2.8 – 12 mm motorized varifocal lens.

Using an example focal length of 6 mm and the RMSE achieved during the validation presented in this report, 4.13 mm, the maximum camera-to-object distance can be estimated as:

$$d = (1 \times 6 \times 4.13) / 0.00252$$

$$d \approx 9800 \text{ mm}$$

$$d \approx 9.8 \text{ m}$$

This indicates that a camera such as the Vivotek FD9383-HTV, configured with a focal length of approximately 6 mm and max resolution, can theoretically achieve measurement accuracy comparable to that observed during validation at camera-to-object distances of up to approximately 10 meters.

Because this camera is varifocal (2.8–12 mm), the theoretical distance scales almost linearly with focal length as shown below.

<i>Focal length</i>	<i>Maximum camera distance</i>
2,8 mm	4.6 m
6 mm	9.8 m
12 mm	19.7 m

If you configure the same camera to a 2MP resolution instead (1920 x 1080), the maximum distances would be:

<i>Focal length</i>	<i>Maximum camera distance</i>
2,8 mm	3.4 m
6 mm	7.4 m
12 mm	14.8 m

This shows that a higher image resolution allows the same measurement accuracy to be maintained at greater camera-to-object distances, provided the sensor size and focal length remain unchanged.

**Determining the Measurement Range for Other Cameras**

The same calculation can be applied to other camera models by substituting:

- The focal length used during operation.

- The sensor pixel size.
- The desired measurement accuracy.

In general, larger focal lengths increase the achievable measurement range. Smaller pixel sizes increase the achievable measurement range. Higher required measurement accuracy reduces the achievable measurement range.

It should be noted that this calculation represents a theoretical photogrammetric limit based primarily on image measurement precision. In practical deployments, additional factors such as residual lens distortion, image compression, motion blur, camera vibration, corner-point placement accuracy, calibration quality and object height above the measurement plane may reduce the achievable measurement accuracy.