IMAGE ORIENTATION & GEOREFERENCING

SLIDES BY B. ALSADIK

UNIVERSITY OF TWENTE.

WHAT WILL WE LEARN?

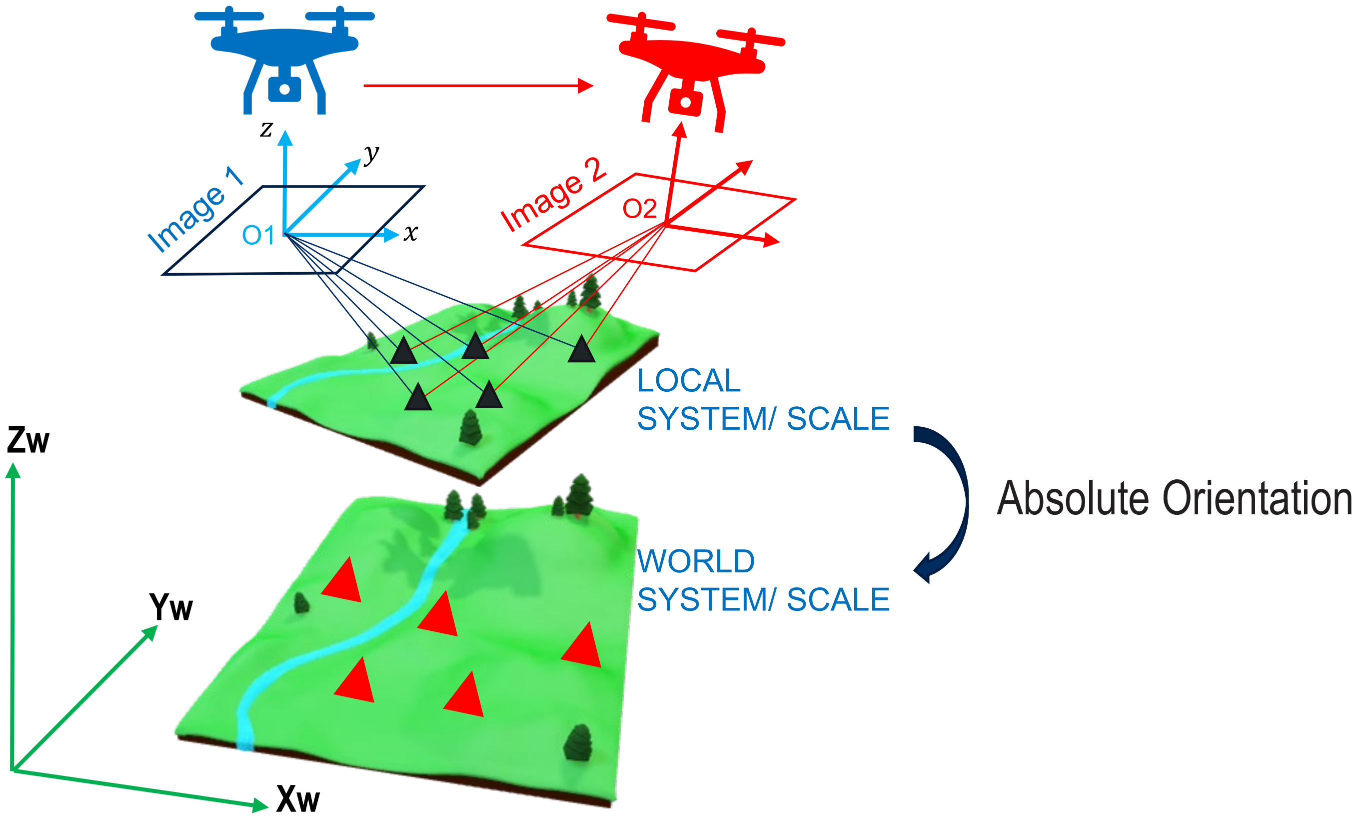
In this lecture we are going to learn several things related to the final mapping products from the UAV images.

The learning objectives are:

- Describe the process of absolute orientation and realize its importance.
- Recognize the Internal and External accuracy assessment of point clouds.
- Realize the sources of error in point clouds.
- Learn some mathematical computations involved to apply the assessment.
- Differentiate the pros and cons of GCPs, PPK, and RTK
- Analyze the quality measures and make some conclusions

ABSOLUTE ORIENTATION

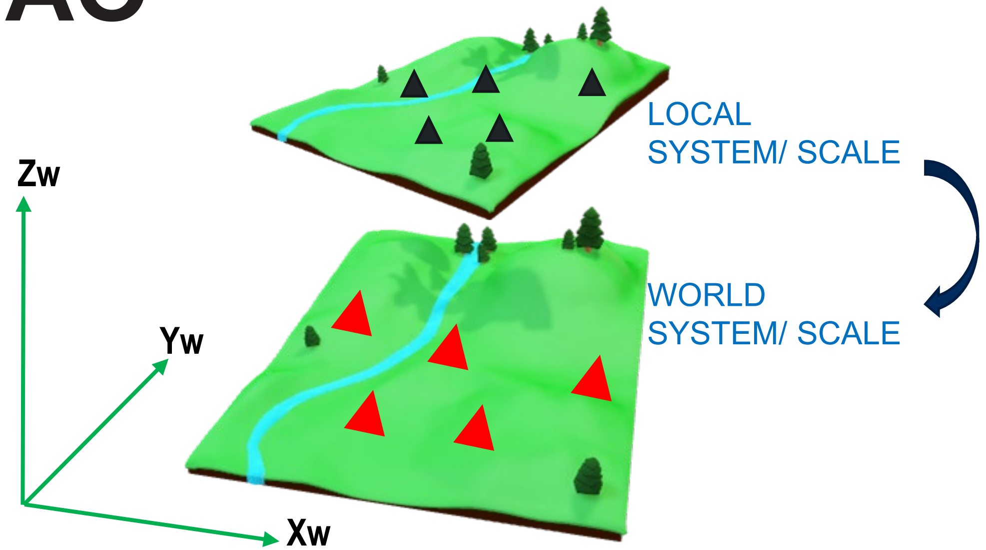
Absolute Orientation AO is aimed to transform the output of RO and triangulated object points into the world coordinate system XYZ.
Transformation means correct scale, rotation and translation



Source: Alsadik. www.ltc.nl

ABSOLUTE ORIENTATION AO

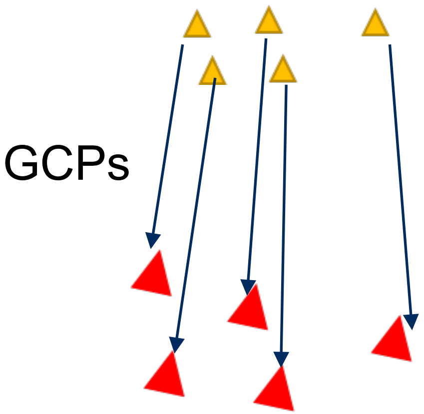
- Absolute orientation is a process of co-registration
- GCPs defined on both systems are required



Absolute orientation problem can be solved by estimating the Rotation, Translation, and Scale.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = s \begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{12} & r_{22} & r_{32} \\ r_{13} & r_{23} & r_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} Tx \\ Ty \\ Tz \end{bmatrix}$$

Absolute orientation parameters



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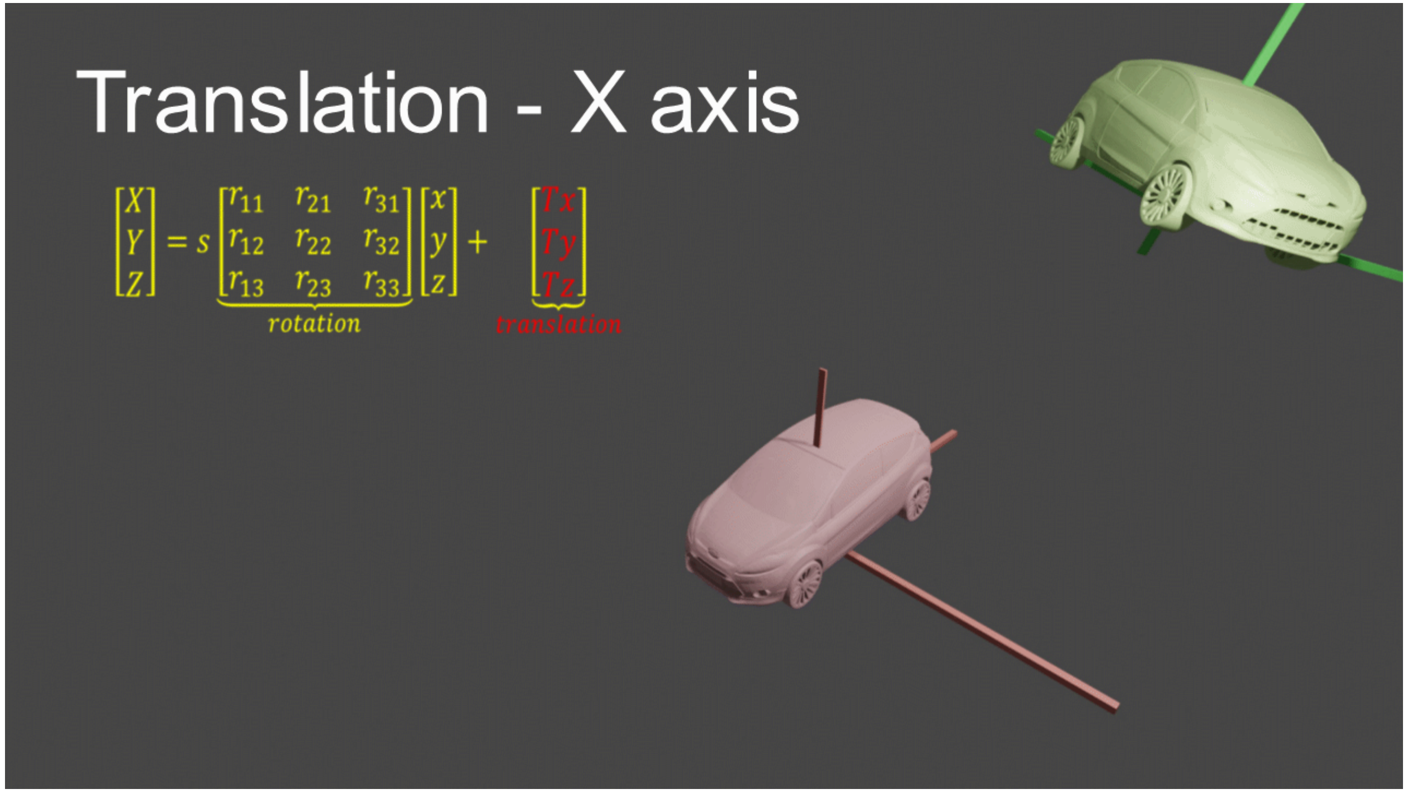
AO IS A 3D TRANSFORMATION

Absolute orientation is a 3D transformation of 7-parameters
3 translations, 3 rotations and a scale.
Least-squares adjustment using either iterative solution or closed form direct solution.



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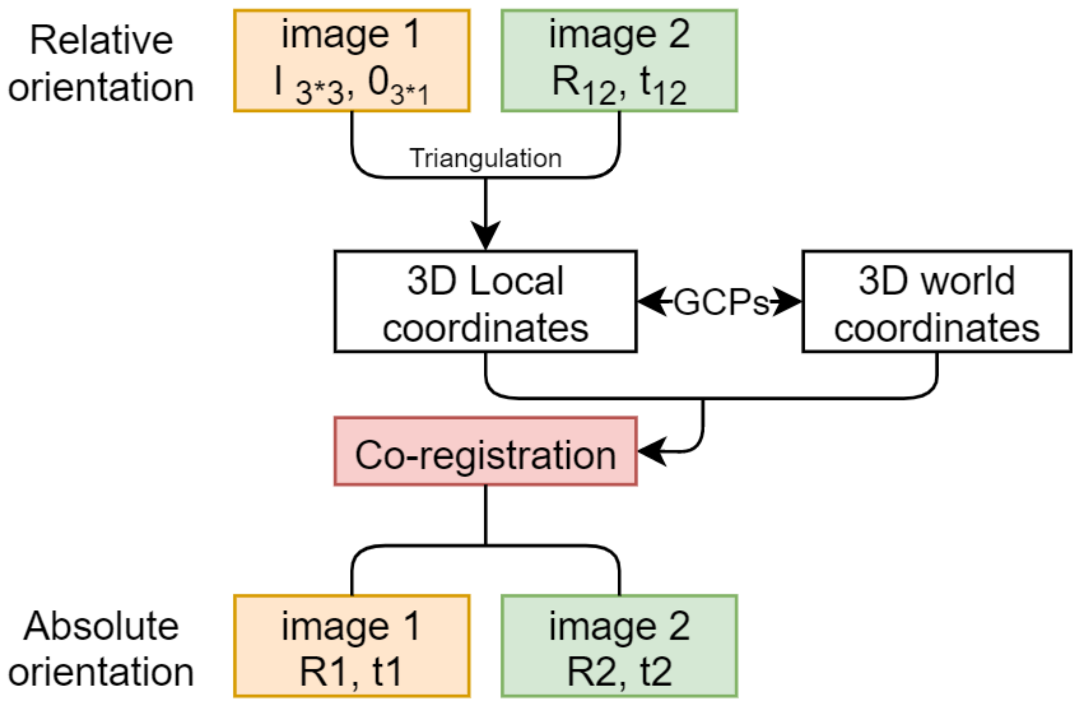
ABSOLUTE ORIENTATION IN A SUMMARY

- Start from the relative orientation by using the fundamental matrix +RANSAC
- Run a triangulation for the scene XYZ points
- Run absolute orientation to make the images oriented with respect to the world coordinate system.
- GCPs are used to achieve the task of 3D coregistration between the local system and the world system

Q/ does this approach accurate enough?
or we need to apply a refinement?



Source: Alsadik. www.Itc.nl

QUIZ

The stereo pair SfM include different steps of (relative orientation, absolute orientation, image matching, triangulation). We want you to select the correct sequence of these computational steps?

a) relative orientation, absolute orientation, image matching, triangulation

b) image matching, relative orientation, absolute orientation, triangulation

c) image matching, relative orientation, triangulation, absolute orientation

d) relative orientation, triangulation, absolute orientation while image matching is not related.

QUALITY ASPECTS OF POINT CLOUDS

➢ Quality assessment can be by evaluated by **Accuracy, Precision, and Reliability**

we need to understand the error types

- **Systematic errors**
- **Random errors**

The point cloud quality can be related to

➢ **Accuracy of individual points**;

➢ **Point density**;

➢ Richness (availability of reflectance/color/waveform);

➢ Gaps/occlusions in the data;

➢ Noise

Which one of athletes is the gold medal winner?

WHY ERRORS EXIST IN UAV POINT CLOUDS?

There are several sources of errors that degrade the quality of the derived point clouds and orthophotos from the UAV images,

The errors can be resulted because of Sensor limitations or processing limitations

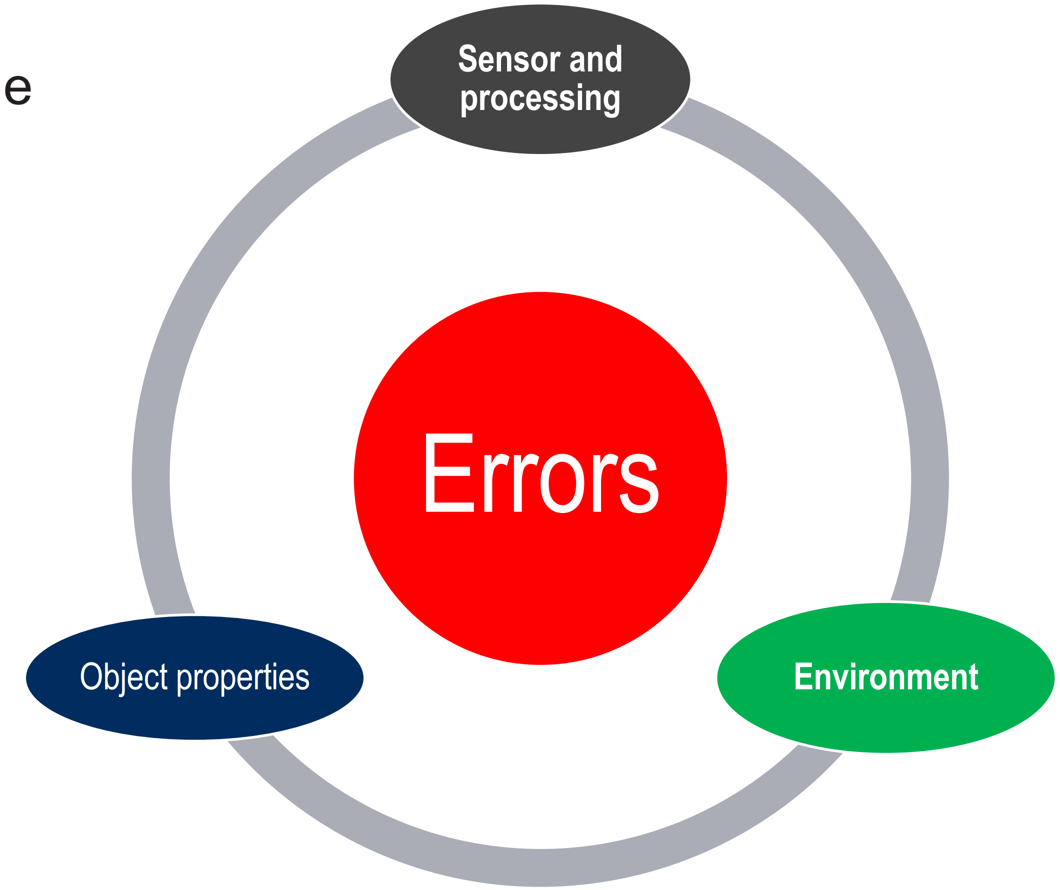


Image-based errors can be

- Camera calibration errors (lens distortion, p.p. offset, …);
- Image orientation error;
- Image matching error;

WHY ERRORS EXIST IN UAV POINT CLOUDS?

There are several sources of errors that degrade the quality of the derived point clouds and orthophotos from the UAV images,

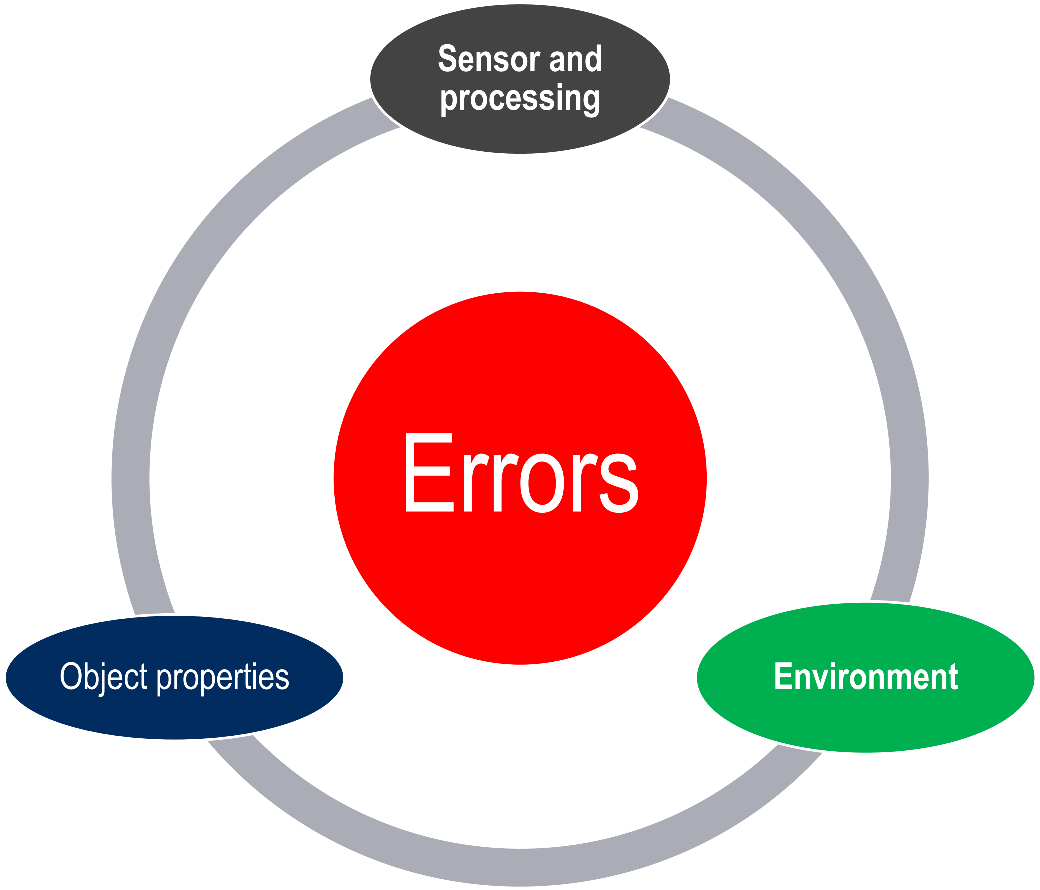
The errors can be resulted because of Sensor limitations or processing limitations

Environment

- **Ambient light;**
- **Humidity;**
- **Dust;**
- **Bad illumination / shadows (images);**

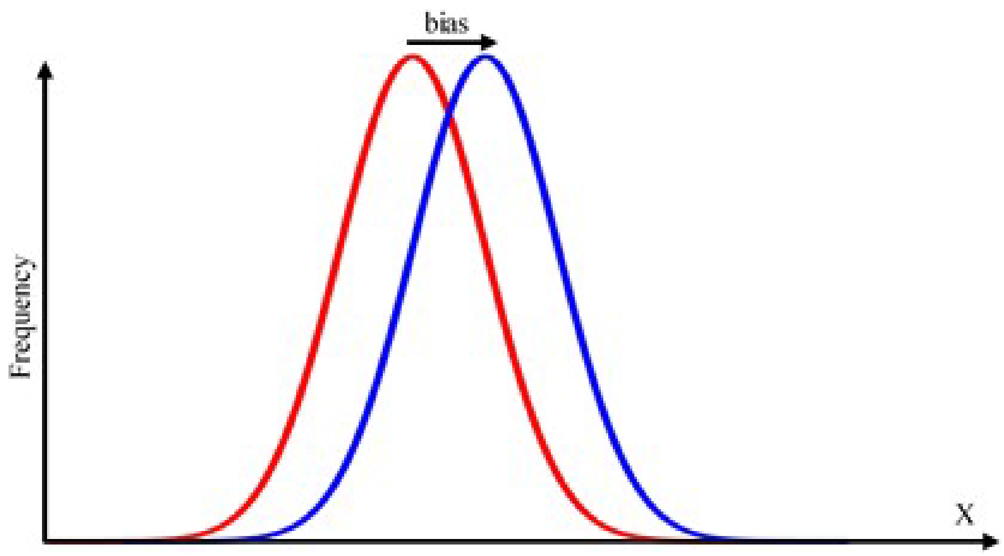
Object properties

- **Surface texture;**
- **Reflectivity;**
- **Scanning/imaging geometry;**



SYSTEMATIC ERRORS

- Either positive or negative.
- Can be eliminated by using proper measuring procedures.
- Systematic errors sources are recognizable and can be reduced.
- The process of the calibration of instruments such cameras in photogrammetry is to detect and remove the systematic errors.



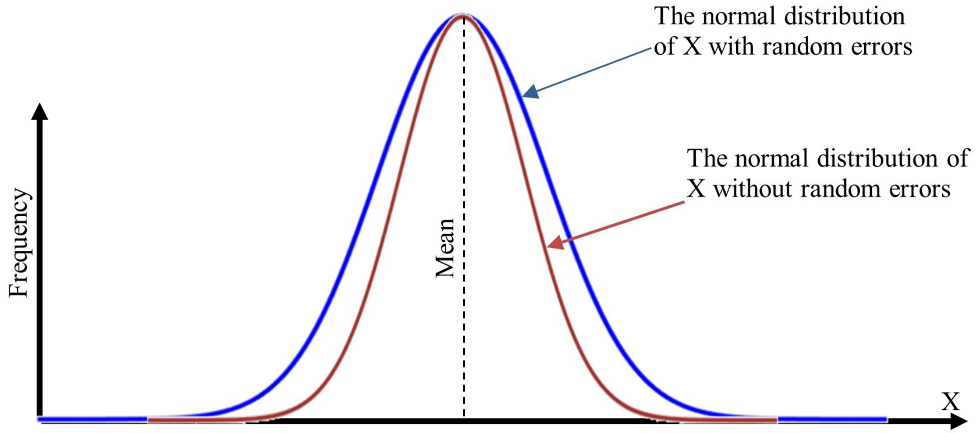
Source: B. Alsadik, Adjustment models in 3D geomatics and computational geophysics : with MATLAB examples, Amsterdam: Elsevier, 2019. [ITC eBook].

systematic error-free observation (red curve) biased in a certain direction and amount (the blue curve).

RANDOM OR ACCIDENTAL ERRORS

Random or accidental errors

- Unavoidable errors which represent the residuals after removing all the other types of errors.
- Occurs because of the limitations in the measuring instruments.
- Can be positive or negative ± and they don′t follow a physical model.
- Therefore, they are processed statistically using the probability theorem since the majority follow the normal distribution.

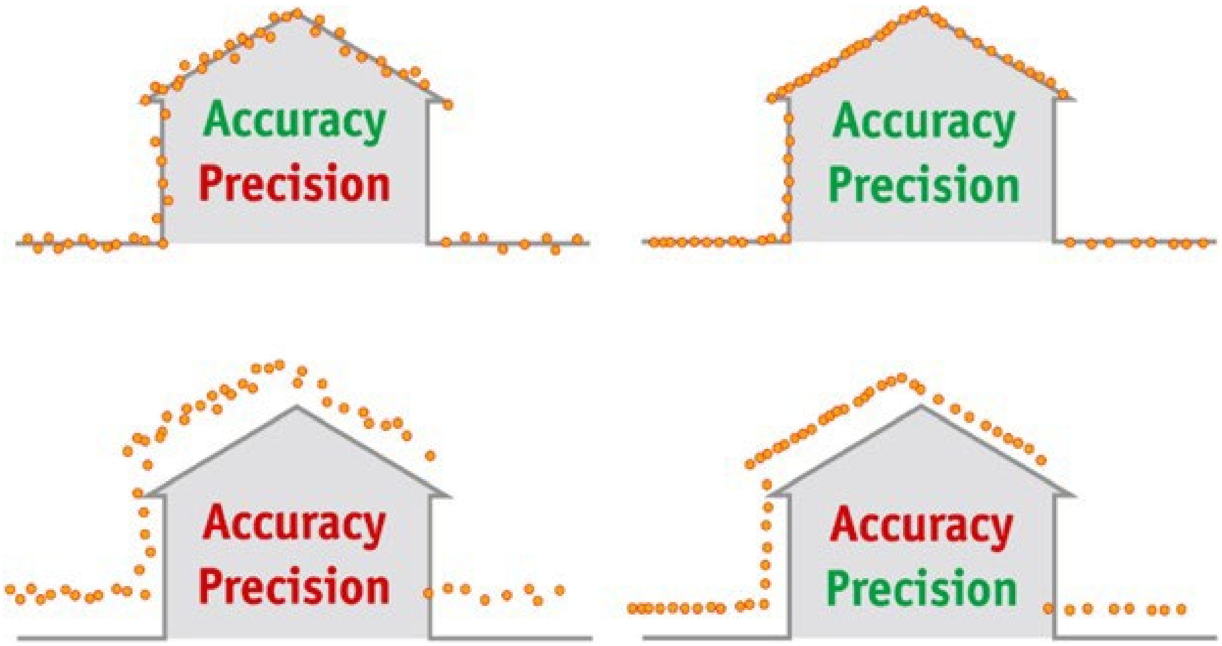


Source: B. Alsadik, Adjustment models in 3D geomatics and computational geophysics : with MATLAB examples, Amsterdam: Elsevier, 2019. [ITC eBook].

- greater random errors cause a greater dispersion of normally distributed observations around the mean.
- The dispersion is measured by the standard deviations

ACCURACY OVERVIEW

- **Accuracy** is a measure of how far the point is offset. An accurate point cloud will be close in average to the actual position.
- **Precision** is the repeatability of the measure. We can consider it as the thickness of the point cloud: A precise poi cloud will be very thin point cloud, with little noise.



https://www.yellowscan-lidar.com/knowledge/wait-accuracy-vs-precision-isant-rocket-science/

Point Cloud form UAV images

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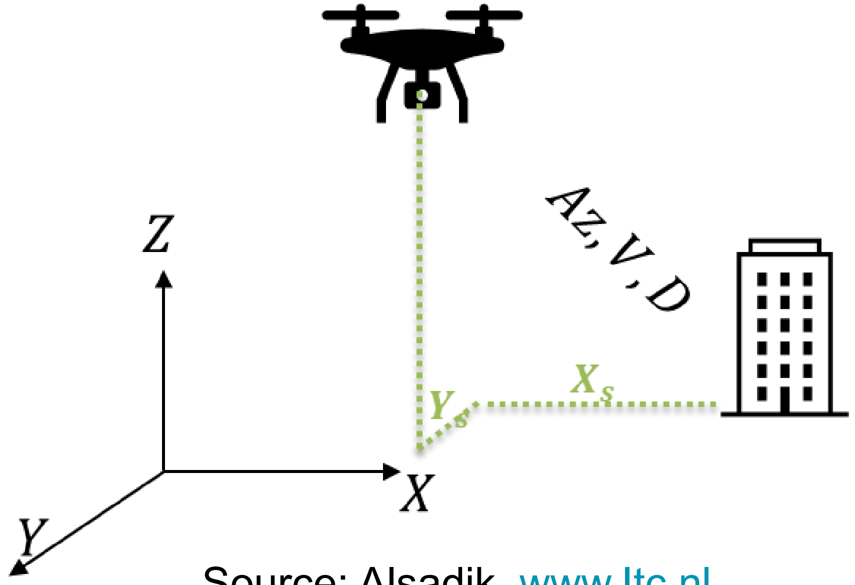
THEORETICAL ACCURACY ASSESSMENT

- Mathematical relation between point coordinates and sensor observations;
- Evaluate point coordinate errors based on errors in observations and parameters in the math model;

- Method: error propagation;
- Should be verified by empirical evaluation

Example: UAV lidar scanning:

$$\begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} = \begin{bmatrix} \mathrm{D}\, cos(Az)\, cos(V) \\ \mathrm{D}\, sin(Az)\, cos(V) \\ \mathrm{D}\, sin(V) \end{bmatrix}$$



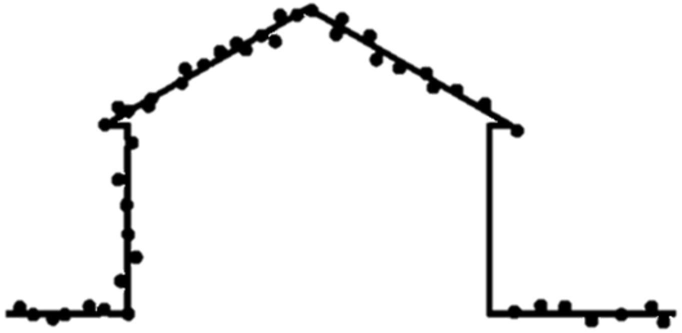
Source: Alsadik. www.ltc.nl

D: the measured range distance
Az: the measured azimuth angle
V: the vertical angle
XYZ_s : the coordinates of the scanned point in the local sensor system.

INTERNAL AND EXTERNAL ACCURACY ASSESSMENT

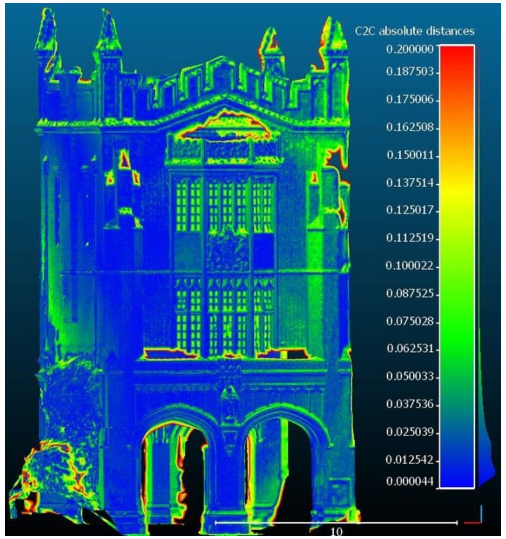
- Internal accuracy assessment (to conclude precision)

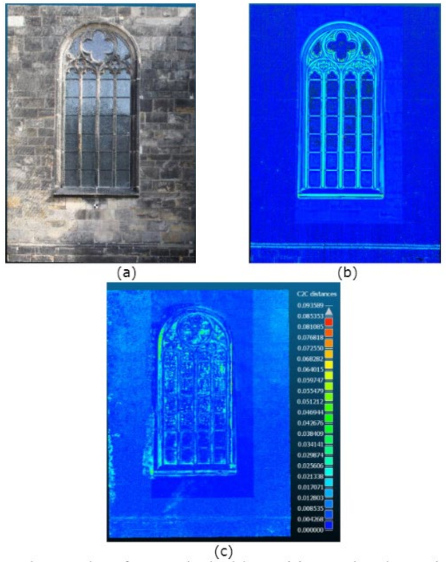
  One approach is to examine the surface properties like the planarity of surfaces.



- External accuracy assessment

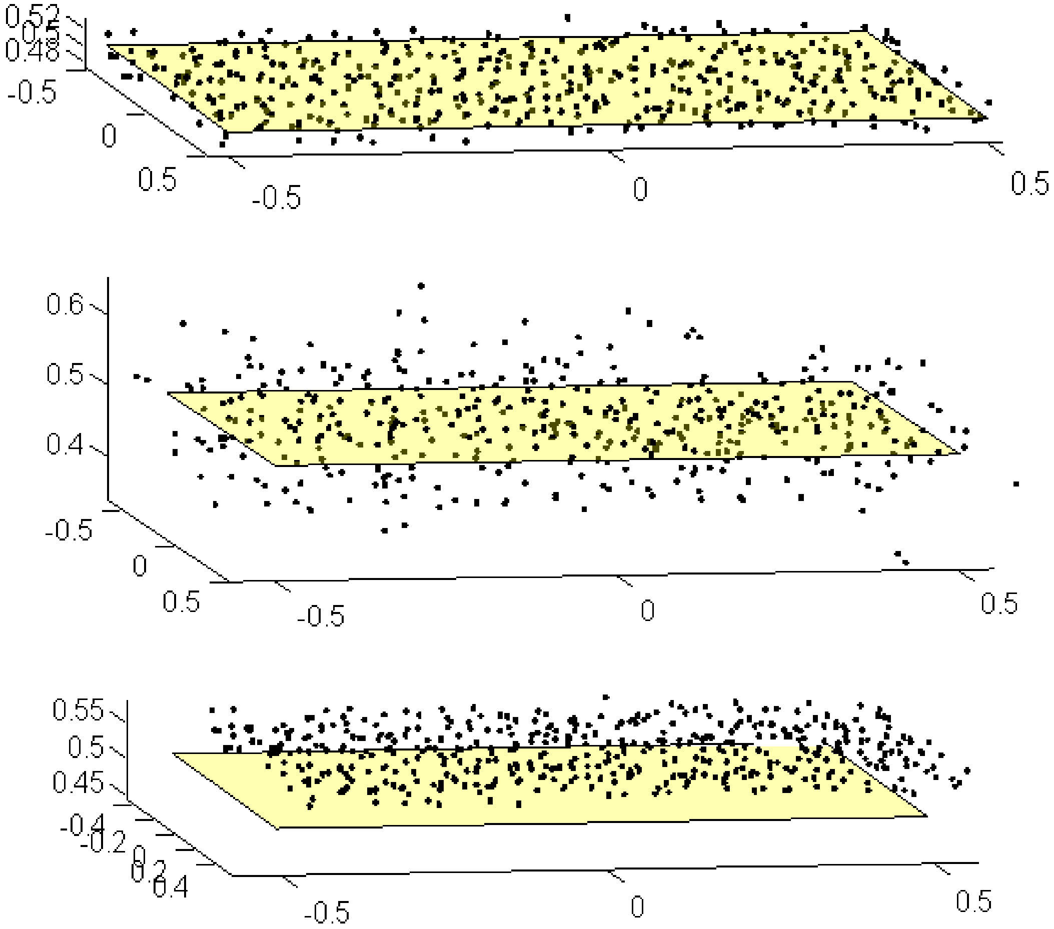
  One approach is to compare with ground truth or a CAD model, etc.



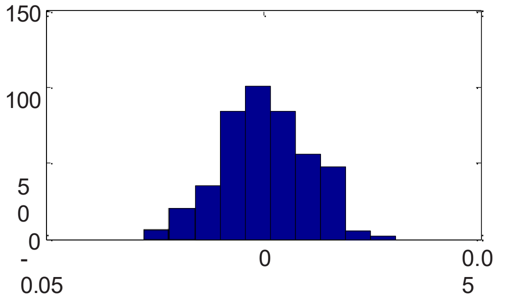


INTERNAL AND EXTERNAL ACCURACY ASSESSMENT

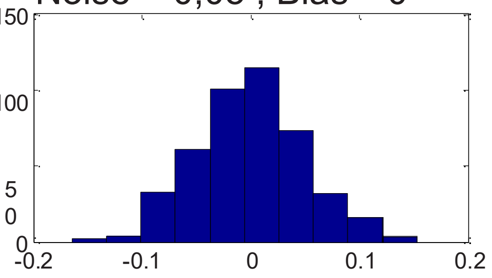
Analyzing histogram of point-plane distances



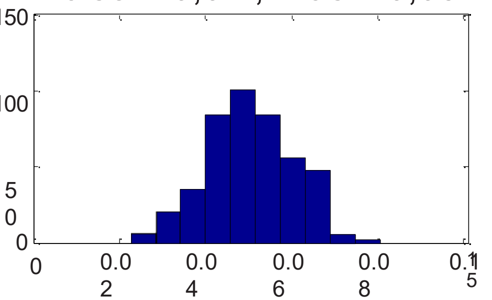
Noise = 0,01 ; Bias = 0



Noise = 0,05 ; Bias = 0



Noise = 0,01 ; Bias = 0,05



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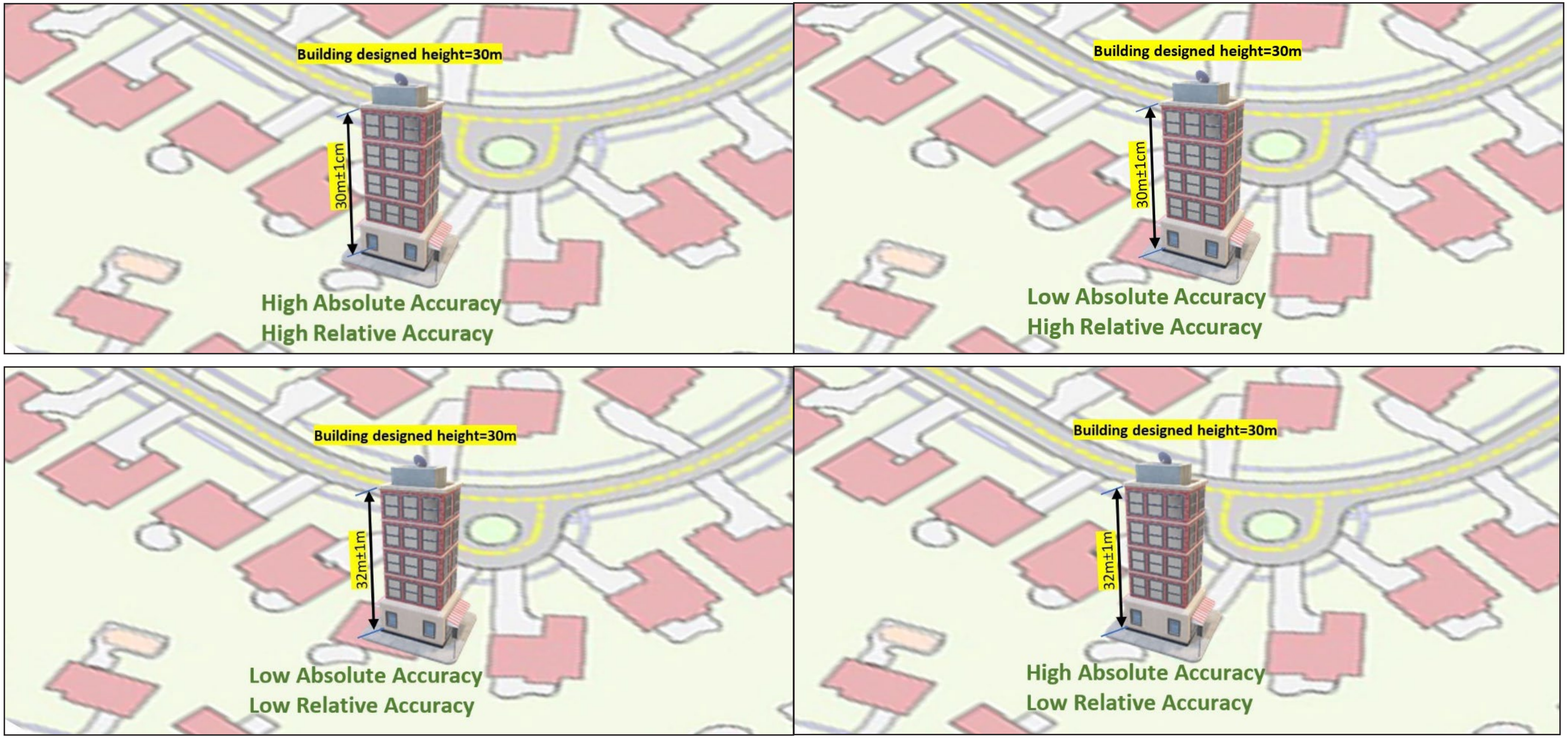
ABSOLUTE ACCURACY

- Absolute accuracy defines how accurately positioned your map is in the world compared to where it truly should be positioned.
- High absolute accuracy is required for land surveys, as-built surveys, and overlaying geo-referenced site plans.
- By correctly utilizing GCPs (Ground Control Points), PPK (Post-Processed Kinematic), or RTK (Real-Time Kinematic) GPS systems, high absolute accuracy can be attained.
- Generally, absolute accuracy when using RTK or GCPs will increase to a maximum of around 2-5cm horizontally, and 4-8cm vertically.
- Generally, absolute vertical accuracy will be around 3 times worse than the horizontal

ABSOLUTE VS RELATIVE ACCURACY

Source: Alsadik. www.itc.nl



The map represents the real world in a specific projection of a reference coordinate system.

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ACCURACY ASSESSMENT USING GCP/CHECKPOINTS

Ground Control Points GCPs are points that are placed on the ground that have known/fixed coordinates.

How to measure/fix the GCP coordinates?
Measure their position (coordinates) using survey-grade equipment like differential GPS or total station

Advantages
GCPs require no RTK-capable drones and a reasonably modest initial expense.

Disadvantages
- GCPs requires field surveying and may the survey cost more money and time.
- May require accessibility to difficult to reach places.
- It is always required to a post-processing.

Source: Dronedeploy

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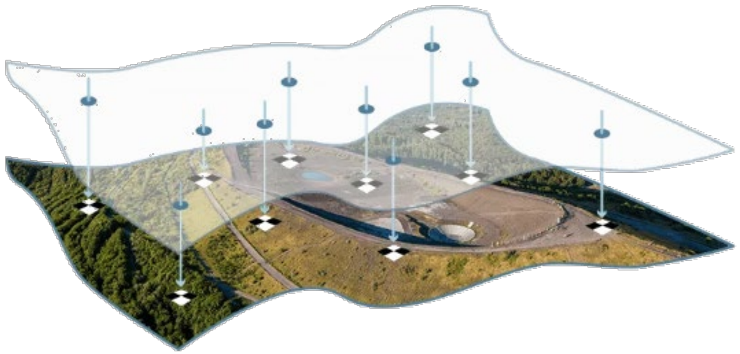
ACCURACY ASSESSMENT USING GCP/CHECKPOINTS

- Some of the Ground Control Points (GCPs), also known as checkpoints, are used to verify the absolute accuracy of maps.
- These checkpoints are not used for processing, but rather to determine the accuracy of the map by comparing the known locations of the checkpoints to their coordinates on the map.
- It is important to empirically validate the relative and absolute accuracy of the map data using Checkpoints.
- The discrepancy between the survey checkpoint position and the computed checkpoint location is known as the checkpoint positional error.



GCP

checkpoint

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Source: wingtra.com

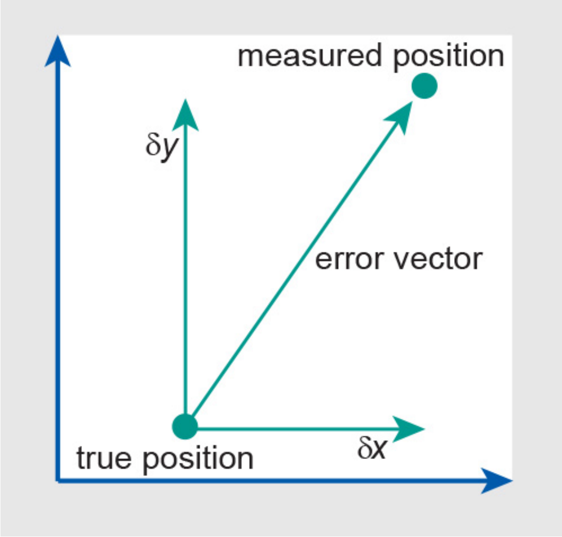
ACCURACY ASSESSMENT USING GCP/CHECKPOINTS

- Usually, Root Mean Squared Error RMSE value is used to check the accuracy.
- The checkpoint XYZ (RMSE) is the average checkpoint location error in the XYZ axis.

$$RMSE_X = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i^O - X_i^C\right)^2}{n}}$$

$$RMSE_Y = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i^O - Y_i^C\right)^2}{n}}$$

$$RMSE_Z = \sqrt{\frac{\sum_{i=1}^{n}\left(Z_i^O - Z_i^C\right)^2}{n}}$$



GCP Label		X Error (ft)	Y Error (ft)	Z Error (ft)
2		-0.0151	-0.0151	0.0945
3		-0.0174	-0.0174	-0.1470
4		-0.0066	-0.0066	0.0423
5		0.0610	0.0610	-0.0220
6		0.0059	0.0059	-0.0039
7		-0.0318	-0.0318	-0.0495
8		0.0039	0.0039	0.0860
Total (RMSE) Excludes Outliers		**0.0277**	**0.0277**	**0.0781**

Source: Dronedeploy

n: total number of checkpoints
O: observed
C: computed

ACCURACY ASSESSMENT USING GCP/CHECKPOINTS

- Checkpoint positional error is a measure used to assess the UAV map's overall accuracy.
- Large checkpoint positioning errors and low absolute accuracy can be caused by systematic errors, although a map may nevertheless have a high relative accuracy.
- It is recommended to place the checkpoints evenly distributed throughout the map.

Q/ what are the conventional techniques to increase absolute accuracy?

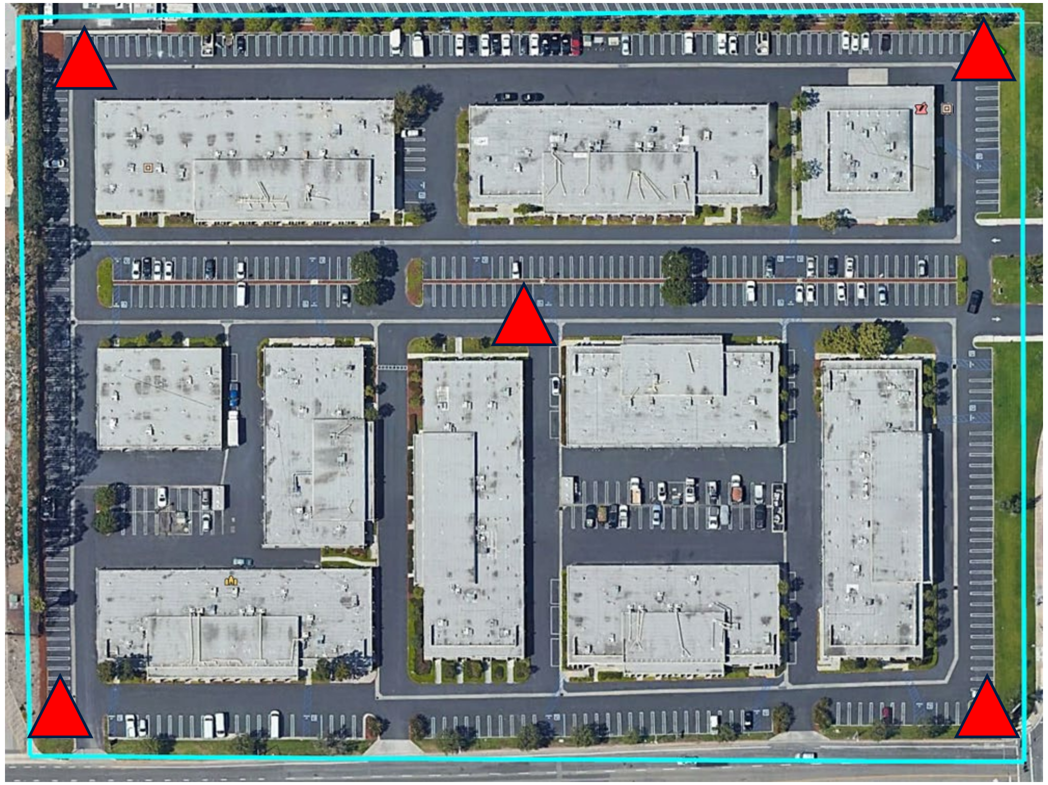
A/

1- Using a Differentiaal GPS: RTK and PPK will increase absolute horizontal accuracy to be of within 1 to 3cm.

2- Using GCPs: adding GCPs and checkpoints will increase the absolute accuracy to be of within 1 to 5cm and related to the GSD

GCP RECOMMENDED DISTRIBUTION

- Good distribution of GCPs improve the acquired accuracy through the entire UAV project.
- Usually, a minimum of 5-6 are recommended for most mapping applications.
- More images have GCPs, the better the accuracy. But the general ratio is 1 GCP per 60 images.
- Generally, we can design 1 checkpoint for every 2 GCPs.
- As shown, 5 GCPs distributed as shown, 4 on the corners and one in the middle is recommended.
- Best to place GCP targets in high and low both areas.



https://www.aerotas.com/

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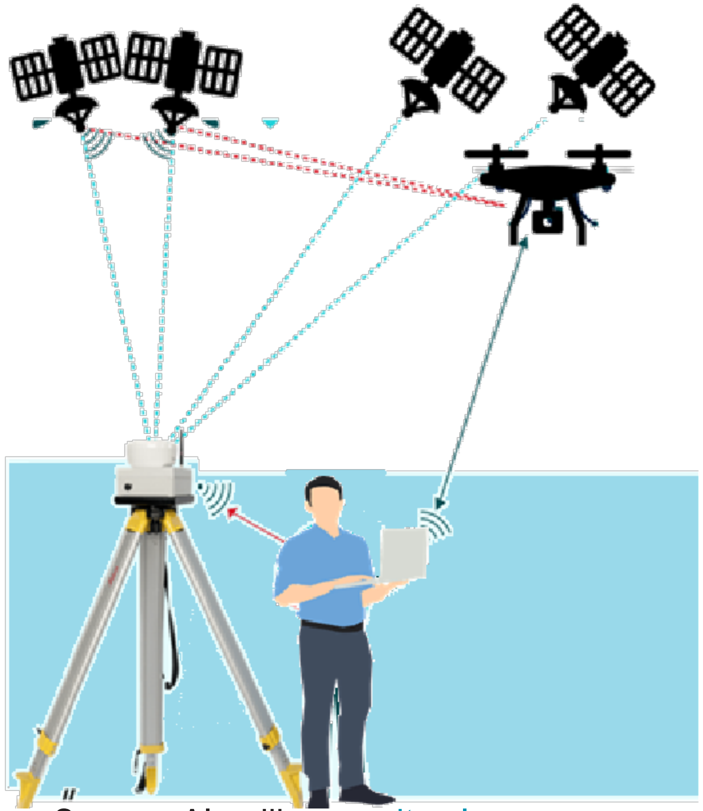
ABSOLUTE POSITIONING USING RTK

- Consumer grade drones using low cost GNSS receivers usually only give accuracy up to 2 to 4 meters.
- One approach to improve absolute accuracy is by using RTK equipped drones.
- Real-Time Kinematic, or RTK, is a method for improving the precision of GNSS (global positioning system) positions by employing a fixed base station to remotely transmit data to a moving receiver.

RTK properties

- Real-time method and real-time corrections for GNSS positions.
- The UAV positions itself using a base station and satellite.
- Post-processing is not needed.
- Reduced data acquisition and processing .
- Fails if signal or internet is lost in the field.
- Requires a base station.
- In UAV RTK projects, only 4-5 GCPs are required generally for every 2 km²

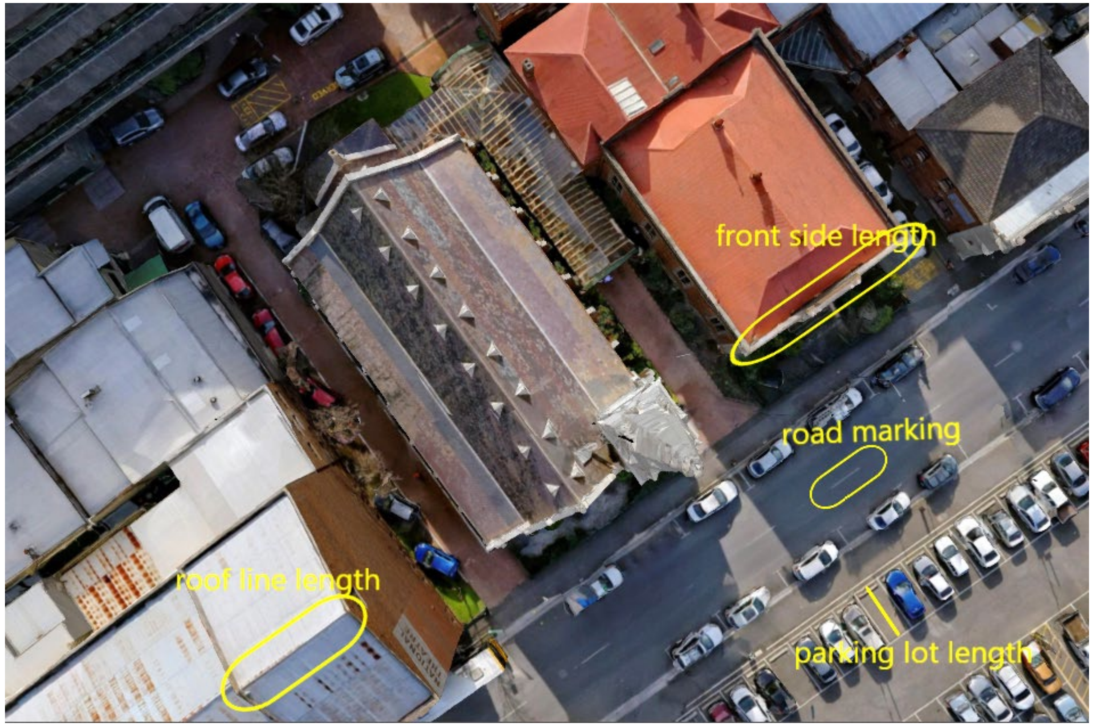


Source: Alsadik. www.itc.nl

RELATIVE ACCURACY

What is Relative accuracy?

How can we check for Relative Accuracy RA?



Generally, it is expected to have a local error around 1 to 3 times the average GSD of the data.

Source: Alsadik. www.itc.nl

- RA describes how accurate measurements within the UAV map/point cloud compared to real life.
- RA is mostly affected by the quality of the image collection and the GPS accuracy of the UAV.
- The RA on UAV orthophoto would still be high even if it were positioned in the wrong geographic coordinates.

How can we check for Relative Accuracy RA?

- Apply field measurements (benchmark) of the dimensions of clearly defined, static objects distributed throughout the UAV map, like the objects circled.

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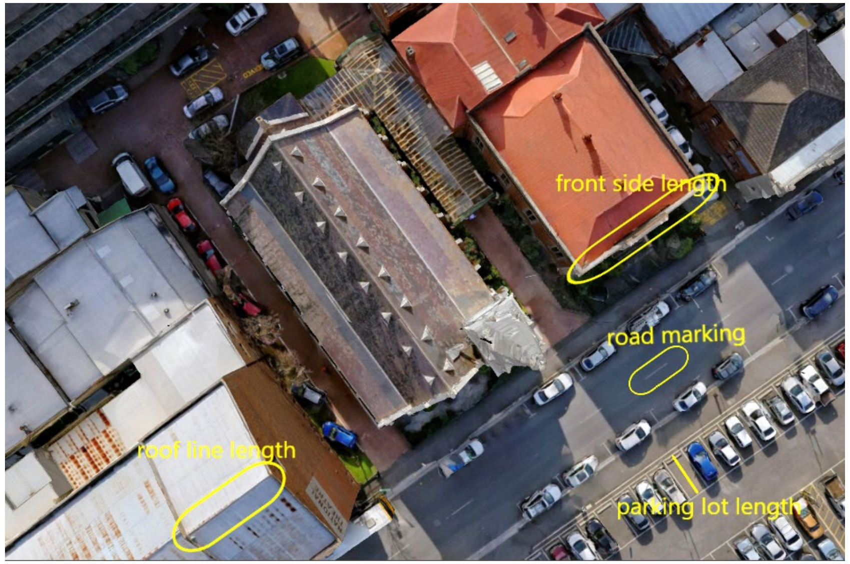
RELATIVE ACCURACY

- Then, measure those exact same features on the finished orthophoto or point cloud.
- RA is then evaluated by calculating the average % difference between the UAV measurements and the field measurements.

In the example below, we have a near **96.7%** RA

Feature	Reference measurements	UAV map measurements	% Diff.
Road marking [m]	3.0	2.9	3.3%
Front side length [m]	4.0	4.2	5.0%
Parking lot side [m]	5.0	5.1	2.0%
roof line [m]	3.5	3.4	2.9%



WHAT HAVE WE LEARNED?

1. What is relative accuracy in UAV photogrammetry? Relative accuracy refers to the precision of measurements taken within a dataset, or the ability to accurately measure a feature viewed in the UAV images.
2. What is absolute accuracy in UAV photogrammetry? Absolute accuracy refers to the accuracy of a measurement in relation to a true or known value, mostly in a specific geographic coordinate system.
3. What is external accuracy in UAV photogrammetry? External accuracy refers to the accuracy of a dataset in relation to other datasets or ground truth.
4. What is internal accuracy in UAV photogrammetry? Internal accuracy refers to the consistency and reliability of measurements within a single dataset.

WHAT HAVE WE LEARNED?

Q/what is the difference between internal accuracy and relative accuracy and give an example?

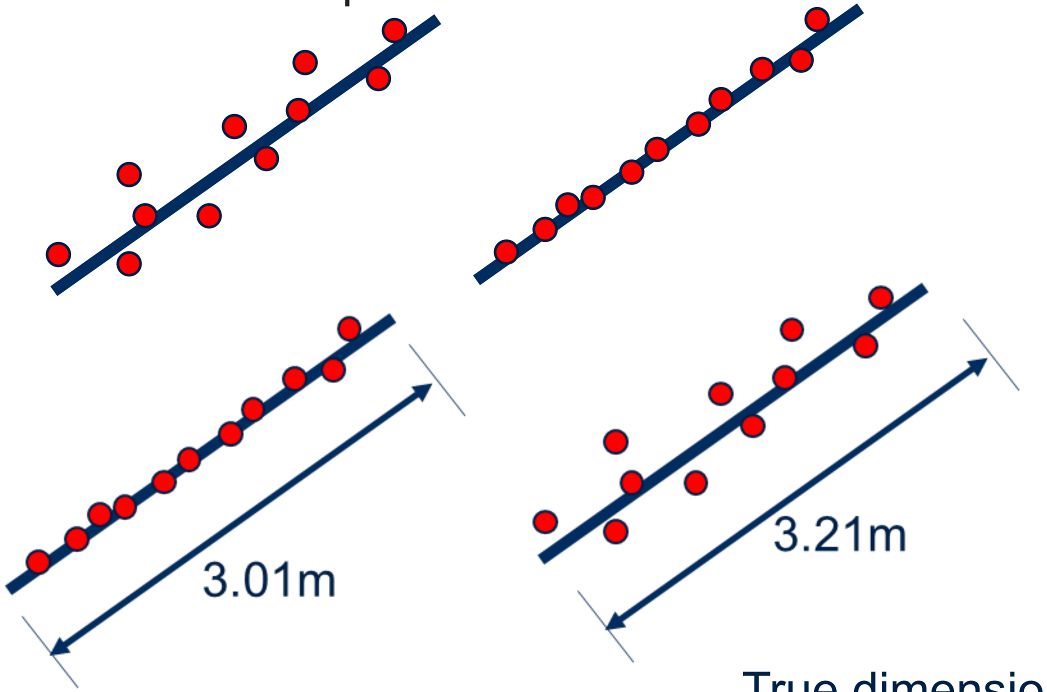
Q/ connect between each figure and the description choices given below

a) Low Internal accuracy

b) Low relative accuracy

c) High Internal accuracy

d) High relative accuracy



True dimension is 3 m

Internal accuracy is concerned with the low noise of points (high precision), while relative accuracy is concerned with the reliability of measurements taken within a UAV dataset.

THANK YOU FOR YOUR ATTENTION
QUESTIONS?