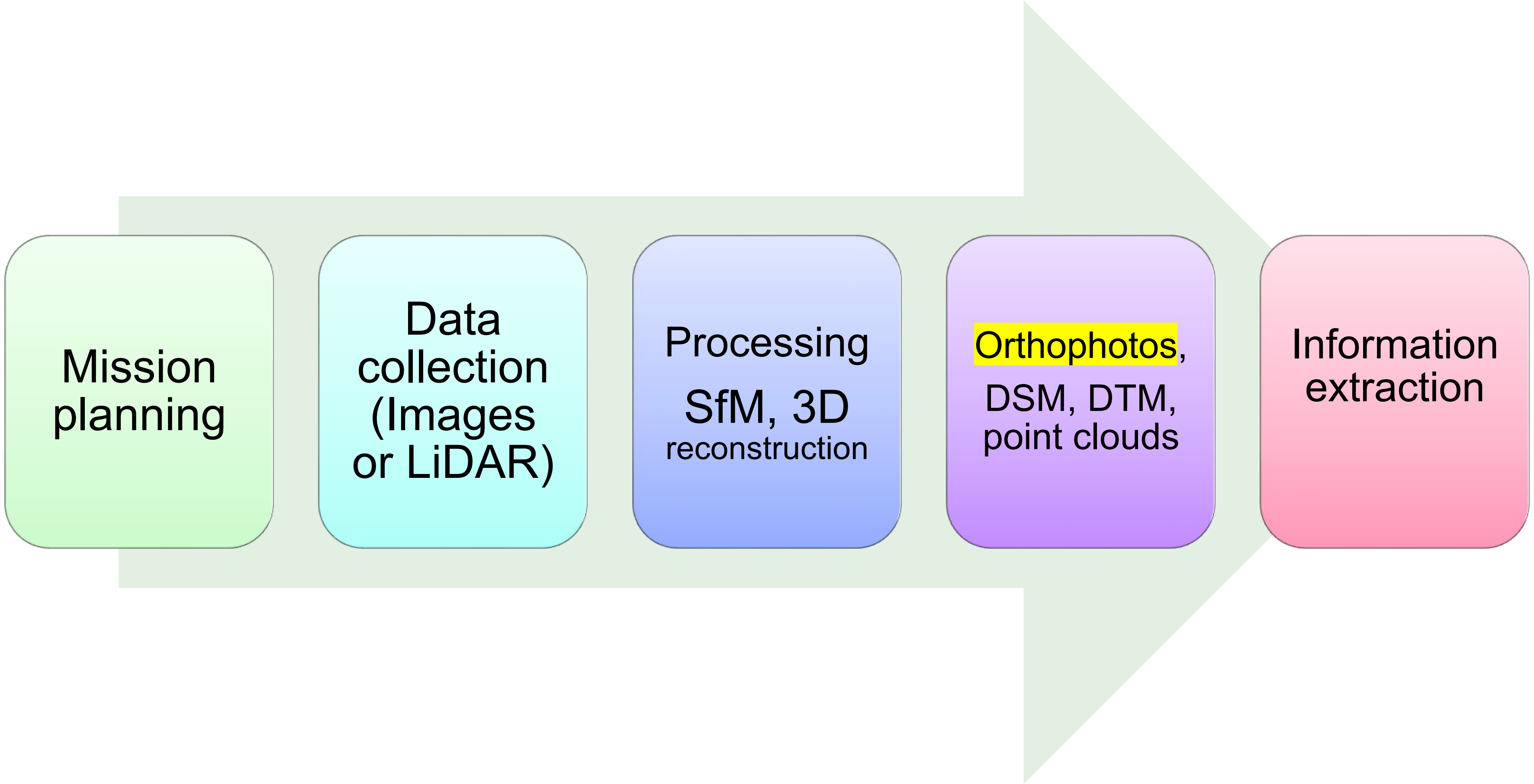
ITC Faculty / Department of Earth Observation Science / Earth Observation with UAVs

Orthophoto + Orthomosaic

Yolla AL Asmar

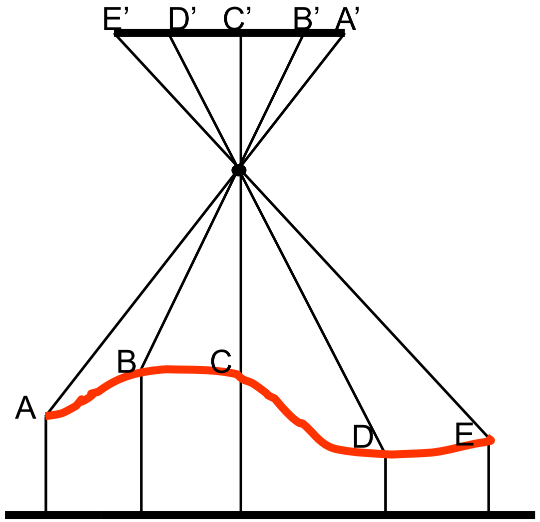
SLIDES BY B. ALSADIK

UAV photogrammetry workflow



UNIVERSITY OF TWENTE.

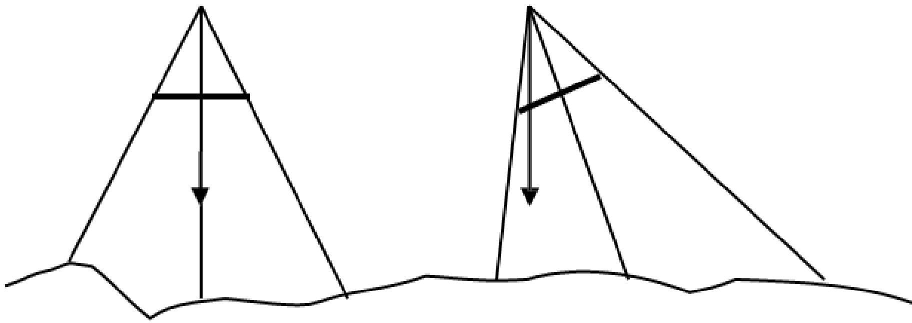
Image perspective distortions



▪An image has a **perspective geometry**: rays of light pass through a perspective center (lens), and are recorded on the image plane;

- Distortion because of Tilt

The scale will be non-uniform over the tilted image compared to the perfectly vertical image on the left.



- Distortion because of relief displacement.

How can we remove the perspective effect from images?

Answer: By removing both distortions mentioned.

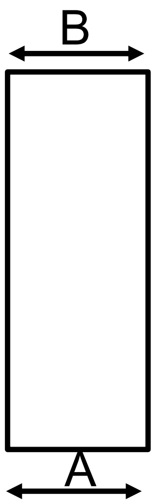
Tolpekin, V., & Stein, A.(2013)

Distortion because of Tilt

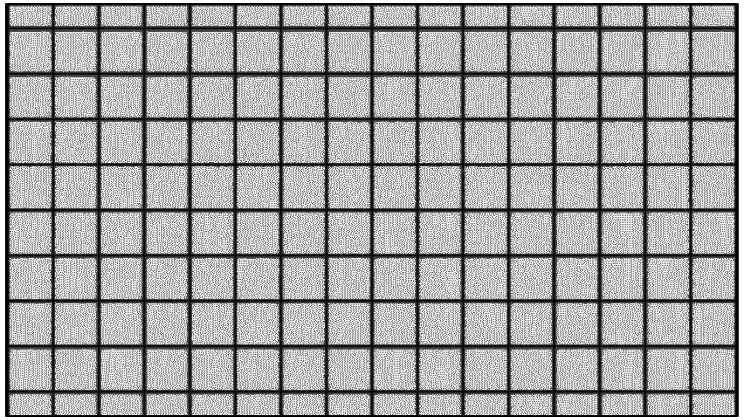
- Tilt can not be fully avoided
- Tilt can be intentional in what is called **oblique photogrammetry**

Vertical image scale is:

$$scale = \frac{focal\ length}{flying\ height}$$



A=B
Scale @ A =Scale @ B

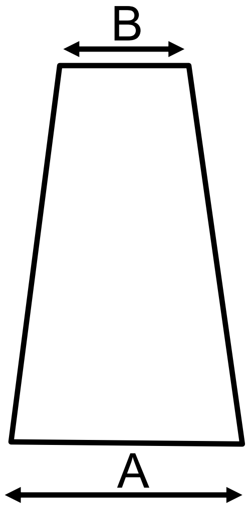


Tilt=0 degrees

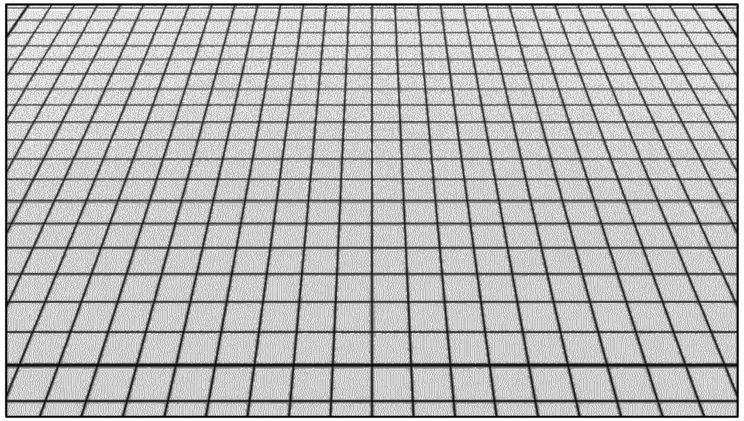
While for a tilted image by angle α, scale will be:

$$scale = \frac{focal\ length}{flying\ height * cos(\alpha)}$$

α is the angle between the camera's axis and the ground surface.



A≠B
Scale @ A ≠ Scale @ B

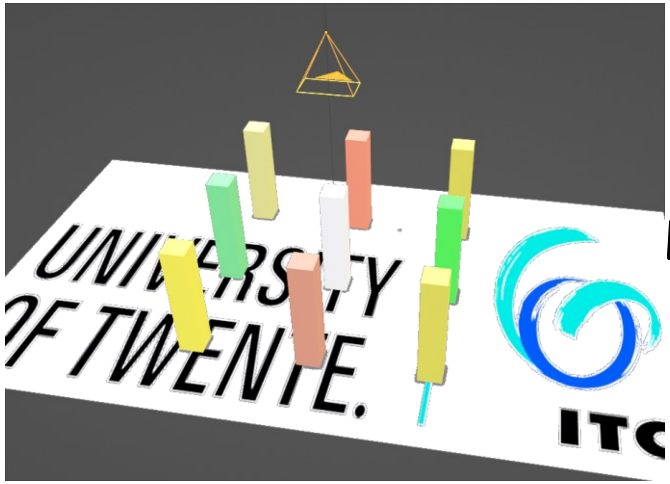


Tilt=45 degrees

Source: Alsadik, itc.nl

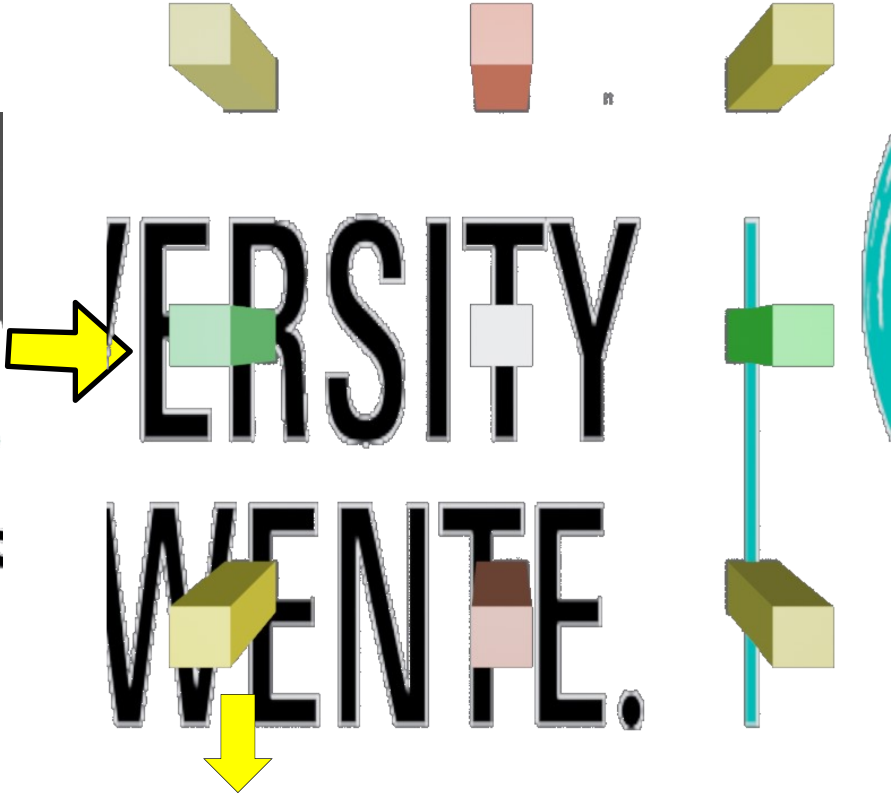
What is Relief displacement?

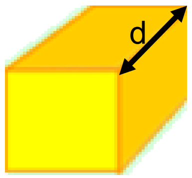
- The radial distance between an object's apparent location in an image and its true location in a planimetric coordinate system is known as **relief displacement**.
- The photos will be displaced in a **direction radial** to the center of the shot if it is genuinely vertical.
- A photo is not a good map since scale variations within any one image are also caused by radial displacement according to relief.



Source: Alsadik, itc.nl

Resulted Image





d=Relief displacement

What is a UAV orthophoto?

- An orthophoto is a UAV aerial image that has been orthorectified and has a uniform scale.
- How the UAV images can be rectified? By geometrically corrected from tile + relief displacement.

Demands and uses of Orthophoto

- **Metric information** : can be used to make **accurate measurements** of distances, areas, and heights. Because the scale of the image is known, measurements can be made directly from the image without the need for ground surveys.
- **Mapping**: They can be used to create accurate topographic maps, land-use maps, and other types of maps such as for urban planning, natural resource management, and emergency response.
- **Change detection**: By comparing orthophotos taken at different times, it is possible to detect changes in land use, vegetation, and other features on the surface.
- **Multispectral analysis**: can be used to create multispectral images that can be analyzed for various characteristics such as NDVI, etc. These analyses can be used to study vegetation health, soil moisture, and other features of the environment.

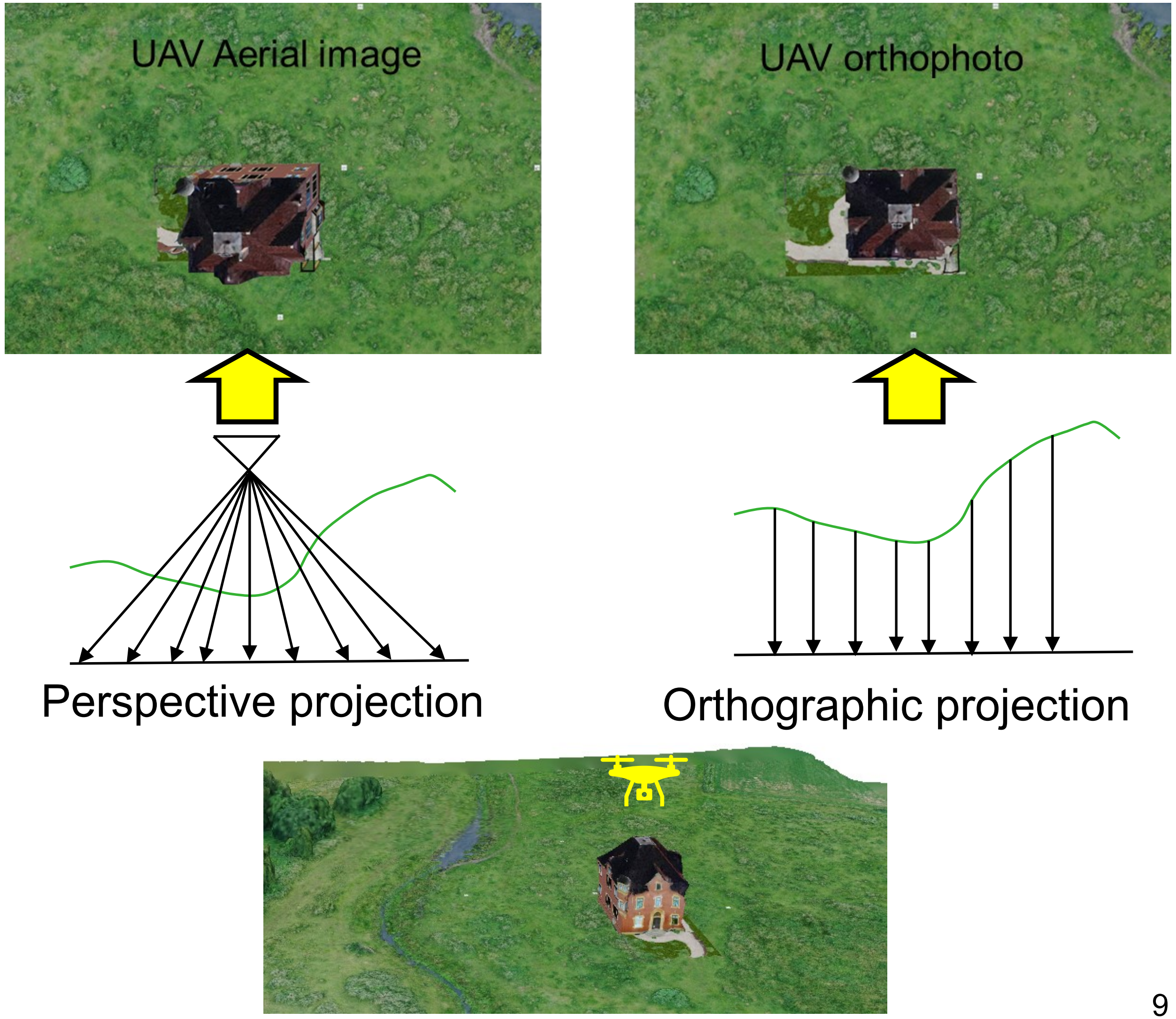
Image vs Map Projection

Are the UAV images nonuniform in scale?

- Yes, because they have **perspective projection,** on the other hand, maps have uniform scale and geometry because features are **orthogonally projected** to the map plane as shown in the slide .

In summary:

- UAV images will have the scale differences all over, and the objects geometry and positions will be distorted.
- While orthophotos will have a constant scale and a true representation of the image geometry.



Source: Alsadik, itc.nl

Orthophotos vs Maps?

- Cheap (& timely) map type product
- More accurate - have true feature representatives
- Have metric information (in a map projection)
- Show high details in a scene with pictorial quality.
- Show seasonal and time differences in a scene.

Source: Alsadik, itc.nl

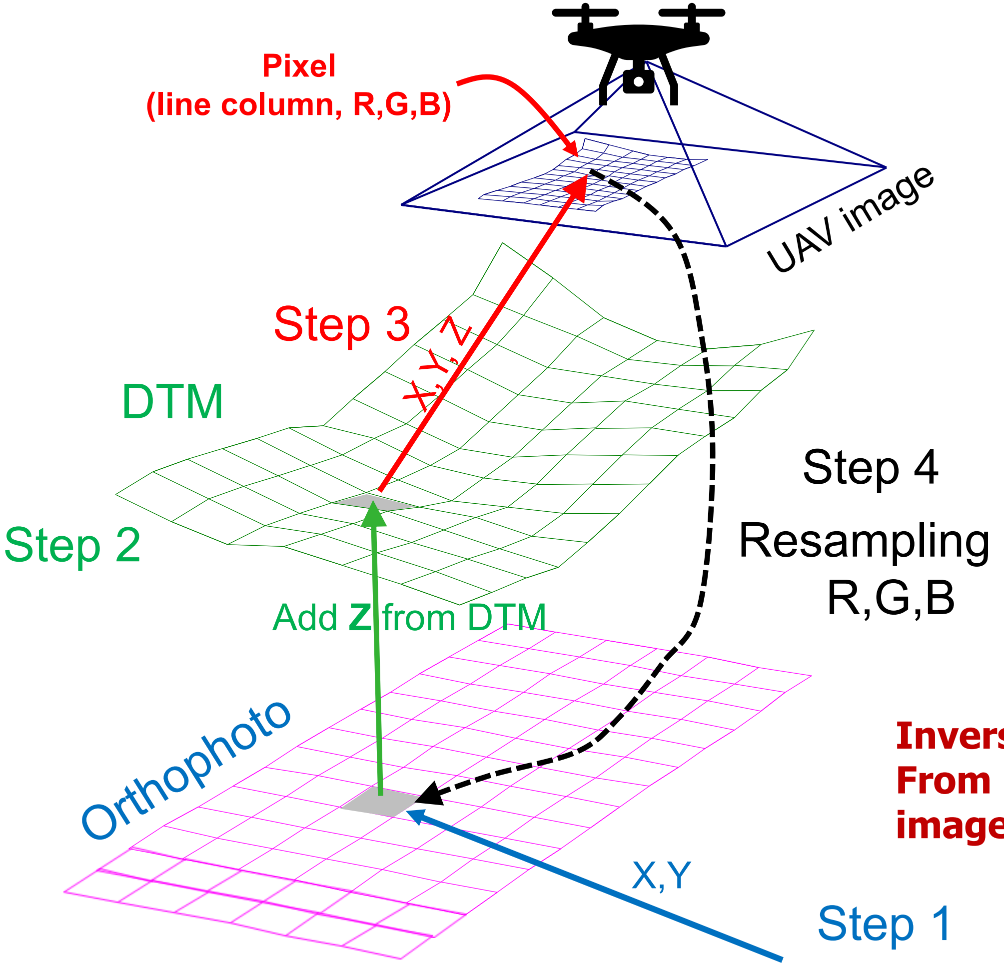
How to orthorectify?

1) from a pre-allocated orthophoto pixel position we get (X,Y) - terrain

2) from a DTM and (X,Y) of step 1, we get Z - terrain (by interpolation)

3) from (X,Y,Z) - terrain and image orientation we get (x,y) - image

4) Resampling: interpolating brightness (or color) for (x,y) - image and assigning it to the orthophoto pixel



Inverse Mapping:
From map coordinate TO image coordinate

First: Initialize the orthoimage with predefined size and resolution over the datum plane

Source: itc.nl

Step 3: from XYZ to pixels

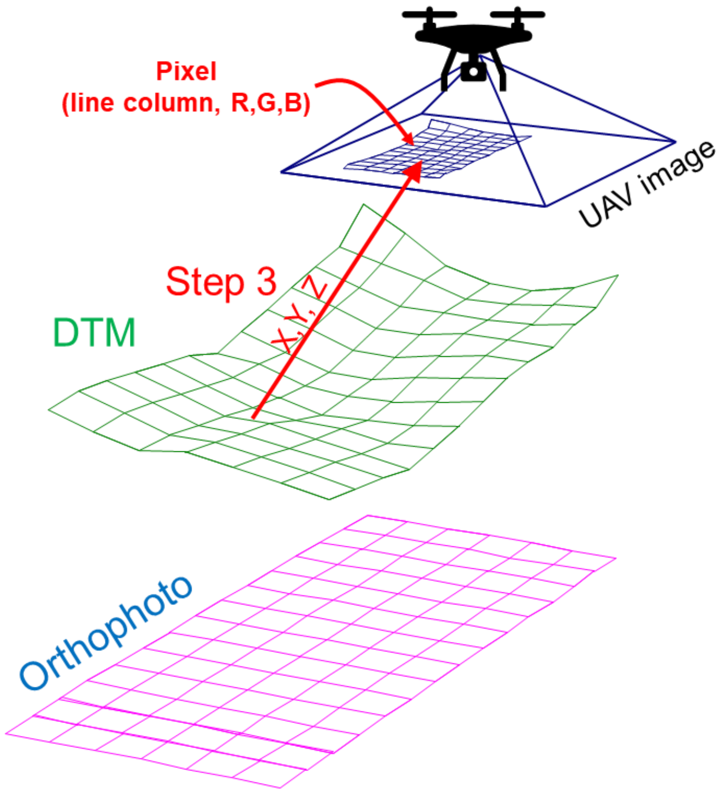
- As we studied in the previous lecture of single image geometry, if the image orientation is determined either as a projection matrix P or as a rotation and translation, then we can simply project the 3D points back to the images.

$$x = PX$$

$$\begin{pmatrix} x \\ y \\ 1 \end{pmatrix} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

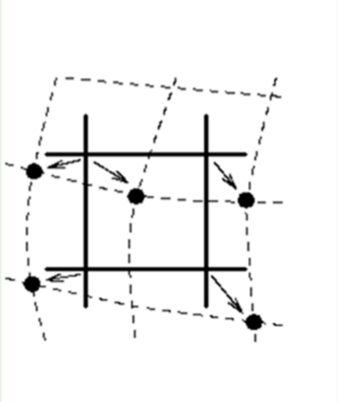
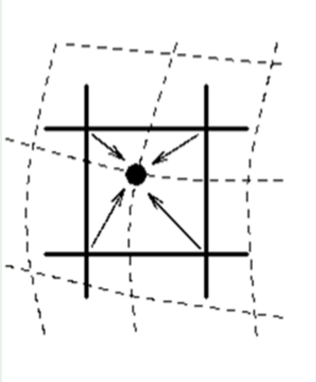
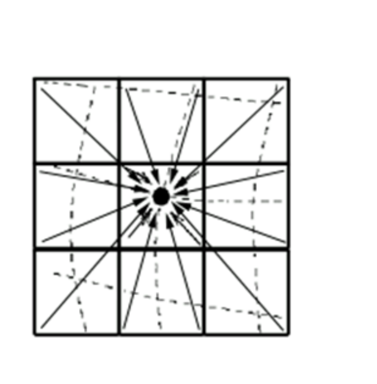
Or

$$\underbrace{\begin{bmatrix} x \\ y \\ 1 \end{bmatrix}}_{3\times1} = \underbrace{\begin{bmatrix} f & 0 & x_0 \\ 0 & f & y_0 \\ 0 & 0 & 1 \end{bmatrix}}_{3\times3} \underbrace{\begin{bmatrix} R_{3\times3} & -R_{3\times3}\, t_{3\times1} \end{bmatrix}}_{3\times4} \underbrace{\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}}_{4\times1}$$



Inverse Mapping:
From map coordinate TO image coordinate

Interpolation methods

Nearest neighbor	Bilinear	Cubic convolution
The value of the nearest original pixel is assigned Preserves image intensity, simple and fast processing	A linear weighted average is calculated for the four nearest pixels in the original image	A cubic weighted average of the values of 16 surrounding pixels is calculated
		

Tolpekin, V., & Stein, A.(2013).

Source: itc.nl

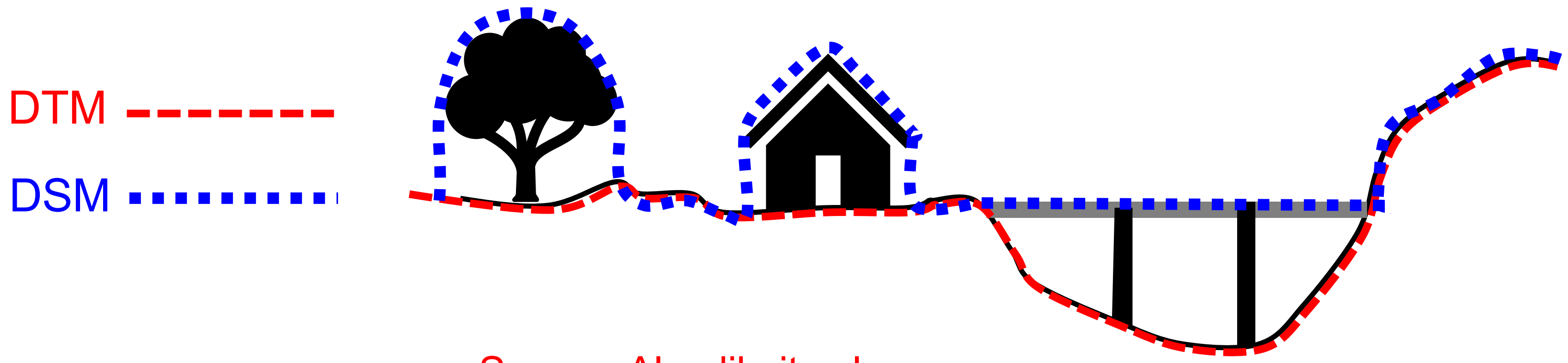
DTM, DSM

- DTM: Digital Terrain Model; Representation of the surface of the earth in digital form;

- DSM: Digital Surface Model. Representation of the terrain surface including objects such as buildings and trees;

The main difference is that DTMs only represent the ground surface, while DSMs represent the entire surface, including any objects on it. This means that DTMs are useful for applications such as terrain analysis, flood modeling, and hydrological analysis, while DSMs are more useful for applications such as urban planning, 3D modeling, and change detection.

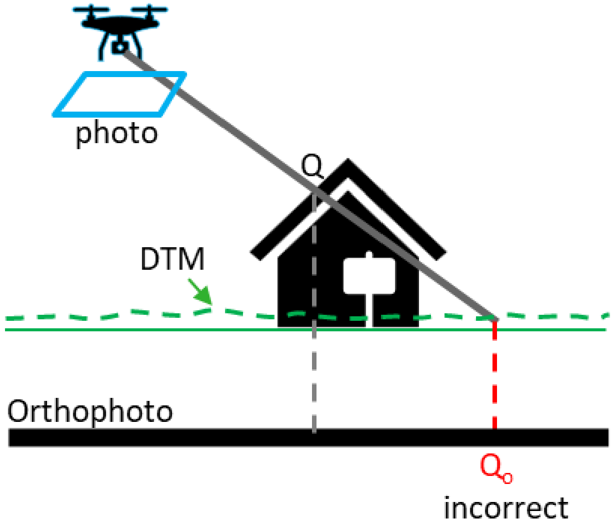
How this impact on creating orthophotos?



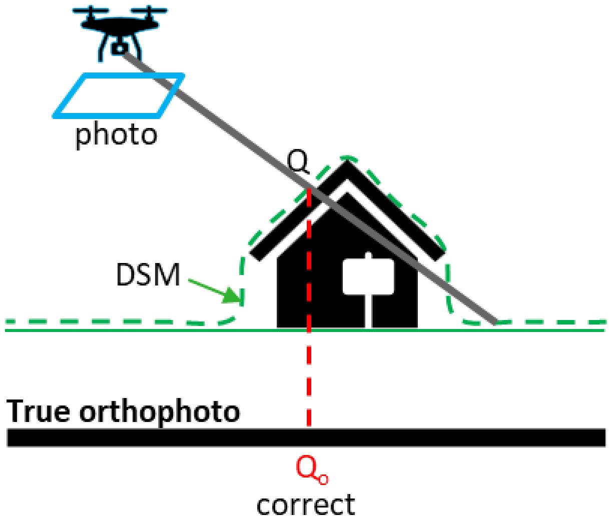
Source: Alsadik, itc.nl

True orthophoto

- **True Orthophoto → Orthophoto using a DSM**
- True Orthophoto gives a vertical view of the earth's surface, removing building tilting and allowing a view of almost any point on the ground.



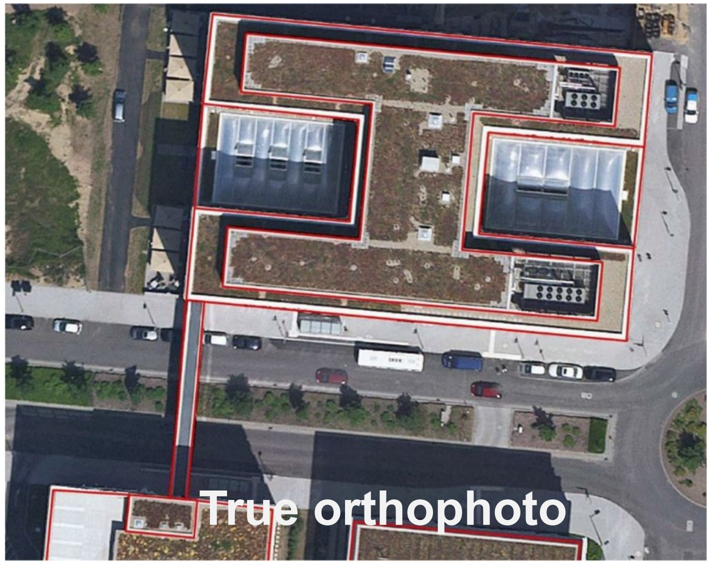
Point which deviates from the (assumed) reference height will show a positional error (relief displacement)

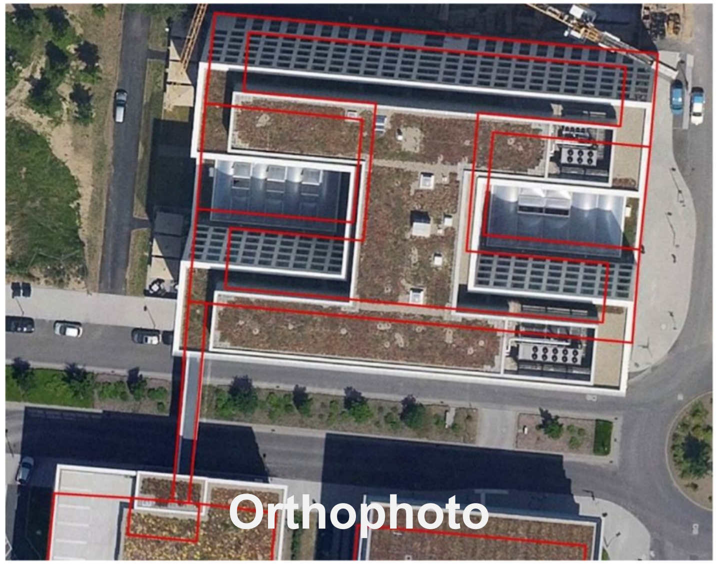


Source: Alsadik, itc.nl

True orthophoto vs orthophoto

- It is simple to recognize **building footprints**, which are consistent with **rooftops in a true orthophoto.**
- True orthophotos have the advantage of not tilting objects that stand out from the terrain, such buildings. As a result, no occluded parts are produced.
- In "normal" orthophotos, tumbling of the images is a common issue that, for instance, impacts multi-story constructions, especially at edge regions.





Source: https://docs.nframes.com/

True orthophoto vs orthophoto

(c) (d)

(c) A portion of the true orthophoto for the Dawson Street study area
(d) the corresponding DTM-based orthophoto.

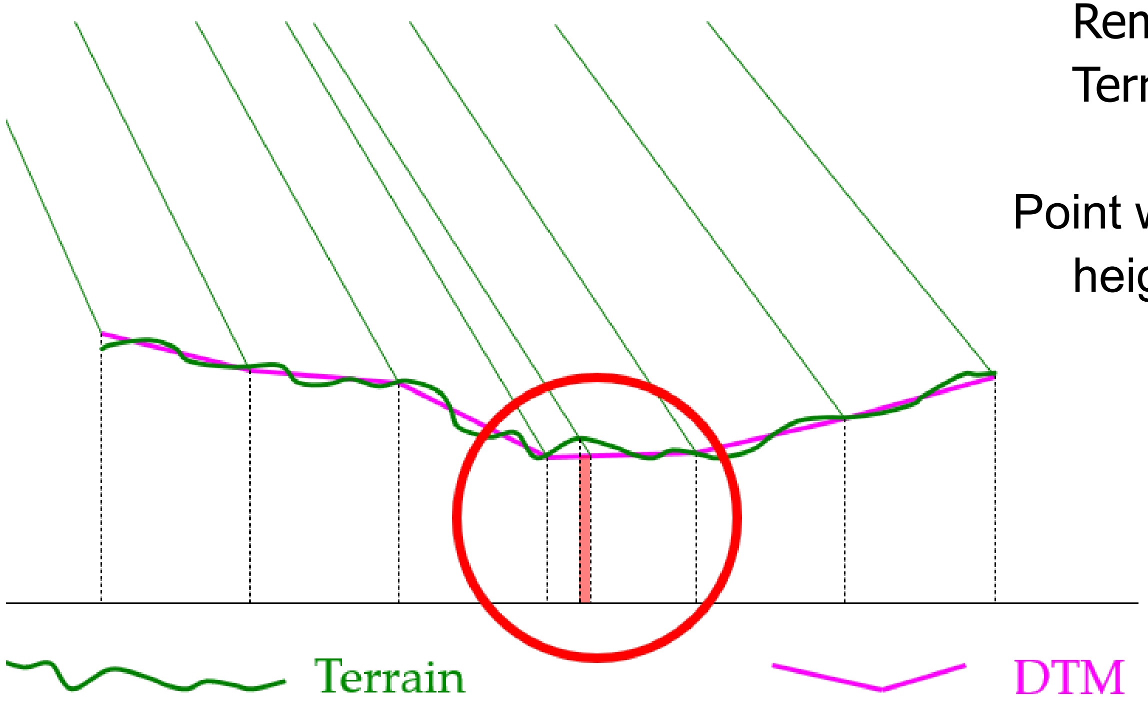
Pixel size is 10 cm in the orthophotos.

(Gharibi and Habib 2018)

Source: itc.nl

Errors of orthorectification

Error in the orthophoto caused by a DTM/DSMerror



Remaining Difference between the DTM and real Terrain (**residual relief displacement**)

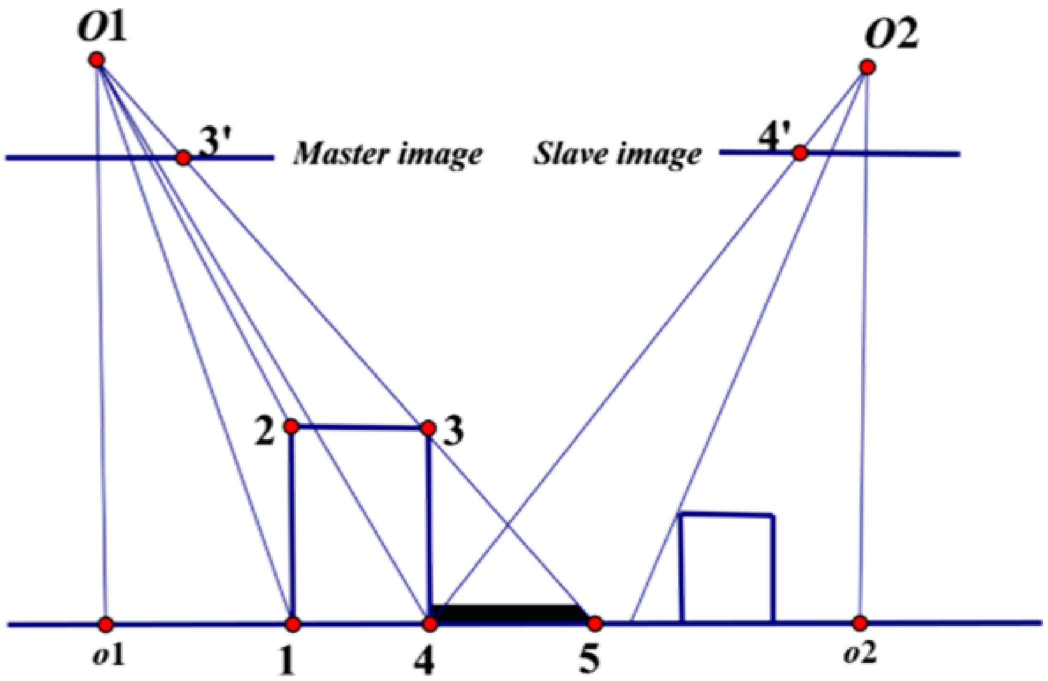
Point which deviates from the (assumed) reference height will show a positional error (relief displacement)

Errors present in the point cloud or DSM generated will be transferred to the orthophoto

Source: itc.nl

Occlusion problem

- The occlusion problem refers to the situation where **objects in the foreground block the view of objects in the background.**
- By collecting UAV images **from multiple flights**, it is possible to capture different views of the same area and minimize the **occlusion problem**.
- By combining the images, they will supplement each other so that the data obscured in one image most likely are visible in another.

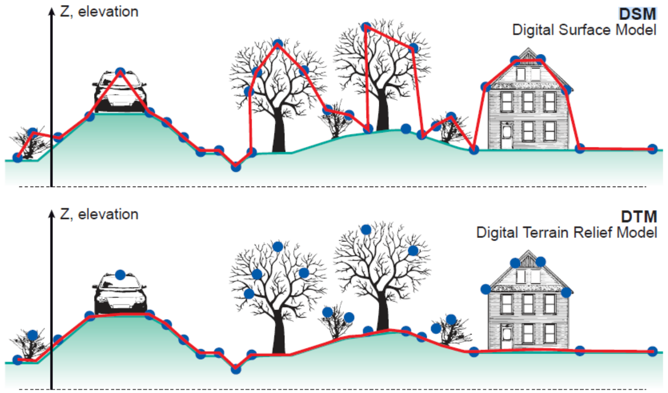


occlusion compensation with neighboring images

Source: Automatic true orthophoto generation based on three-dimensional building model using multiview urban aerial images.

Problem caused by a multi-valued surface

Both DTM and DSM can only represent single-valued surfaces



Tolpekin, V., & Stein, A.(2013).

conventional orthophoto (from DSM)

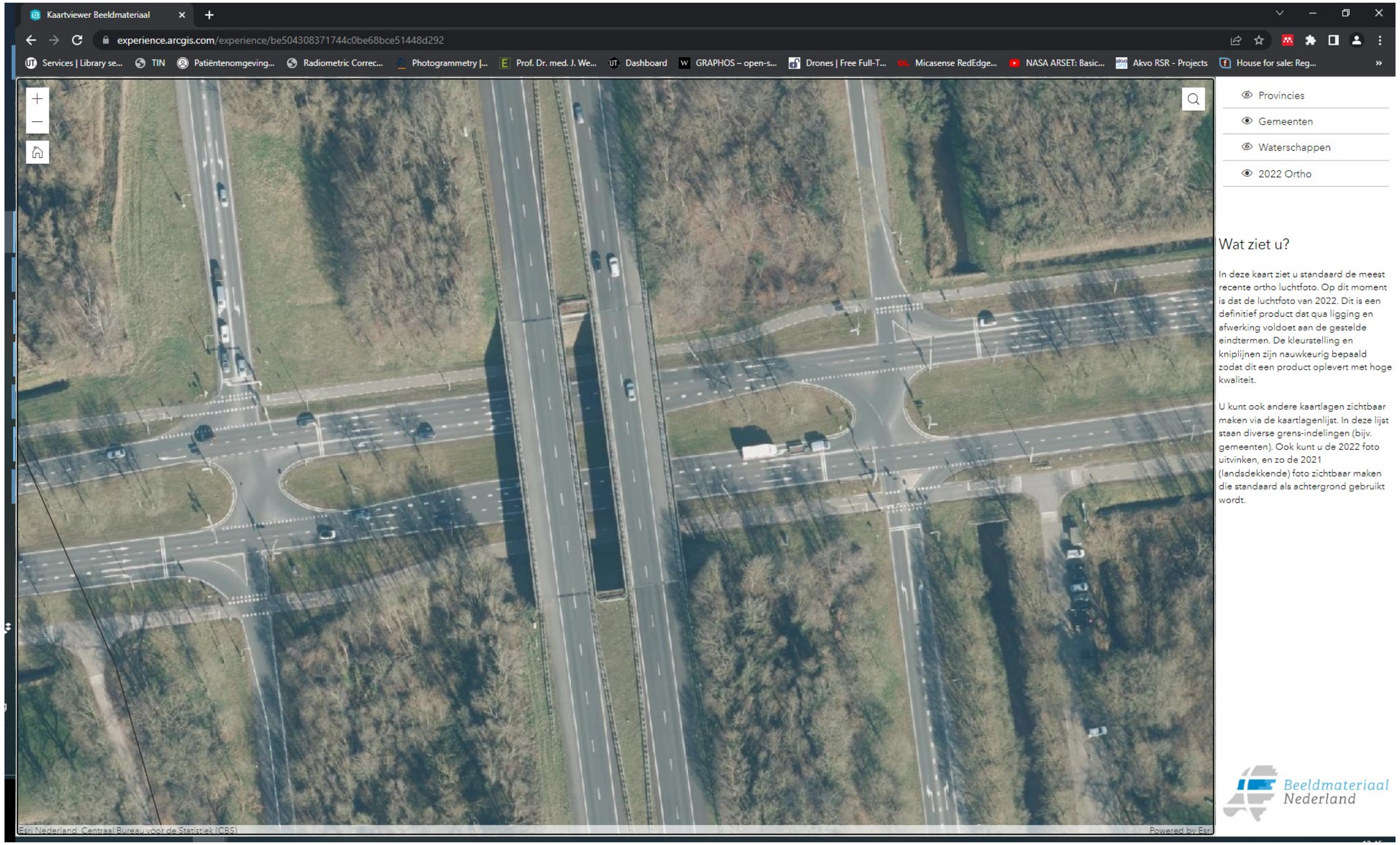
manually corrected orthophoto

Image source: undetermined

Source: itc.nl

Another example

Link: https://experience.arcgis.com/experience/be504308371744c0be68bce51448d292



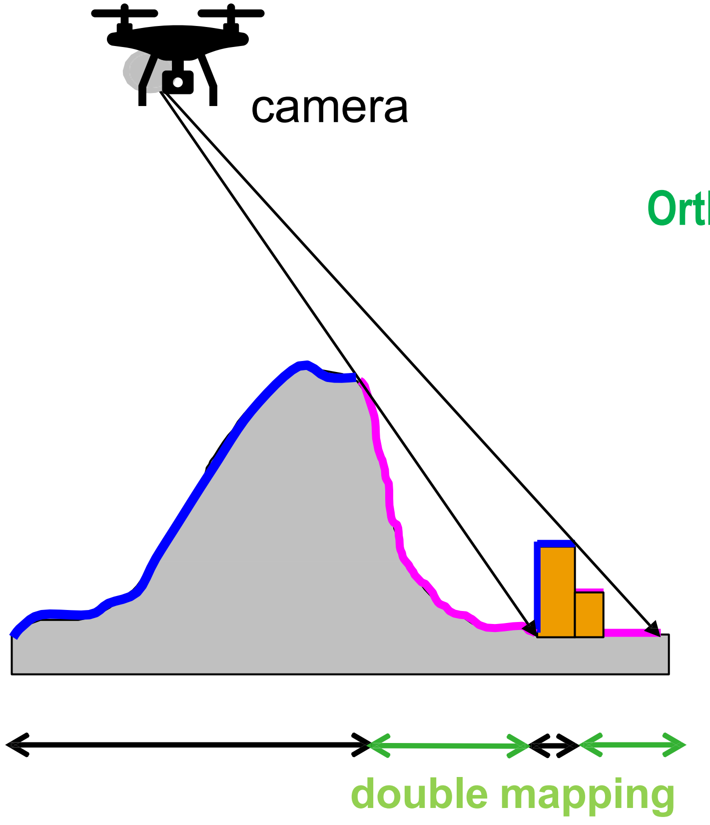
Credit: Beeldmateriaal Netherland
https://www.beeldmateriaal.nl

Source: itc.nl

Double mapping effect

When the same ground point is mapped to two or more distinct pixels in the final orthorectified image, this is known as the **double-mapping problem**

- Double-mapping in orthophotos can occur whether a DSM is used in the orthorectification process.
- Double mapping is more related to the **visibility application** of the points to finally have a true orthophoto.



Source: itc.nl

Original image

Orthophoto

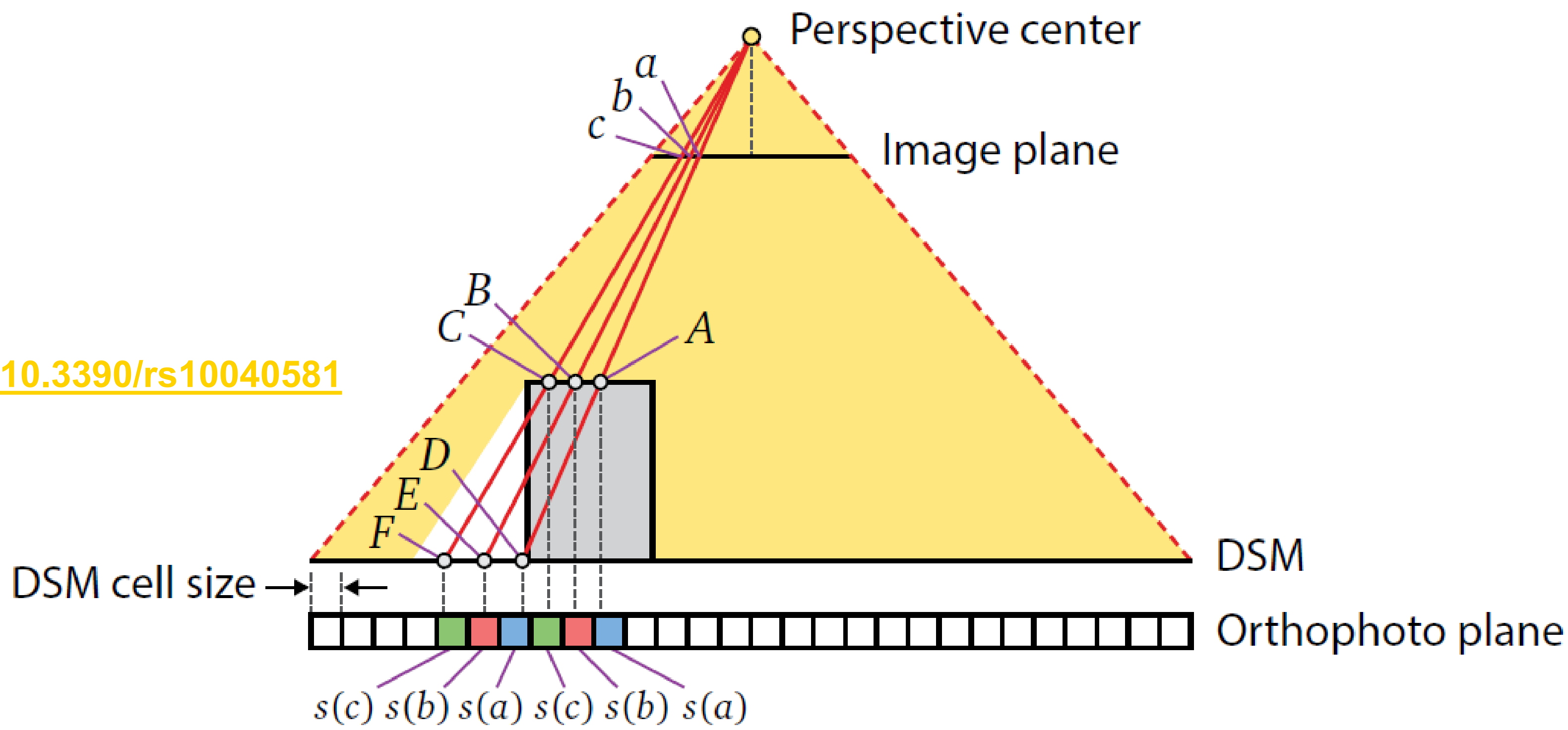
Oliveira, Henrique & Habib, Ayman & Dal Poz, Aluir & Galo, Mauricio. (2015).

imaged area
obscured area
correctly mapped area
doubled mapped area

Double mapping affect – clarification

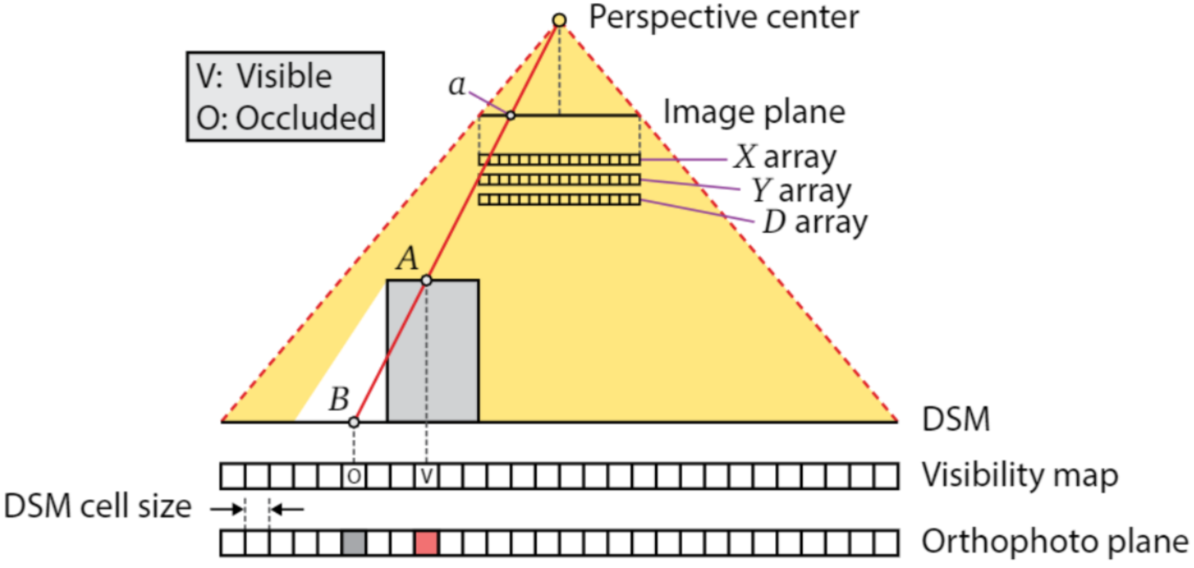
- **A, B, and C** are corresponding areas to DSM cells which **are visible** in the image
- **D, E, and F** are corresponding areas to DSM cells which **are not visible** in the image- occluded by the adjacent building.
- DSM cells **A, B, and C** are projected to locations a, b, and c in the image and assigned the spectral information (s(a), s(b), and s(c))) to the orthophoto pixels corresponding to **A, B, and C** respectively.
- DSM cells in the occluded area **D, E, and F** are also projected to the image locations a, b, and c and s(a), s(b), and s(c) are assigned to the orthophoto pixels at **D, E, and F**

https://doi.org/10.3390/rs10040581



Visibility testing

- Visibility testing is a method used to determine which pixels in the image **should be used to represent a given point on the terrain**, in order to minimize the double-mapping problem.
- In urban areas with complex buildings **visibility analysis** with the use of **Digital building Model DBM becomes necessary.**
- The **Z-buffer algorithm** is the most efficient and popular visibility method for detecting occluded areas in a true orthorectification.



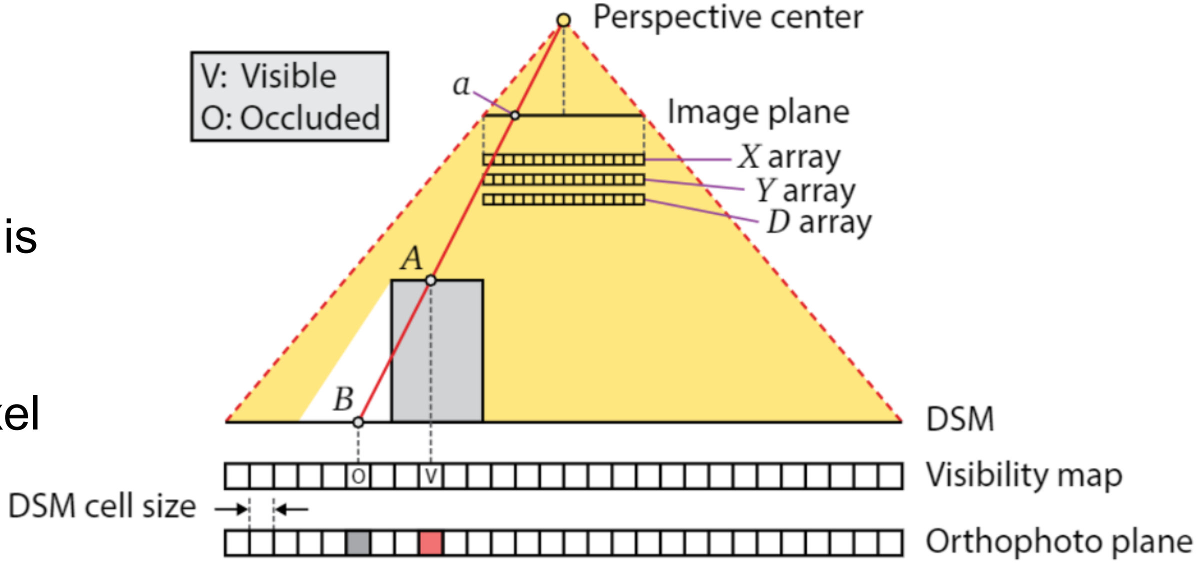
https://www.mdpi.com/2072-4292/10/4/581

Z-buffer technique

- **The Z-buffer method counts the number of DSM cells projected to a certain image pixel to count occlusions.**

Z buffer algorithm steps:

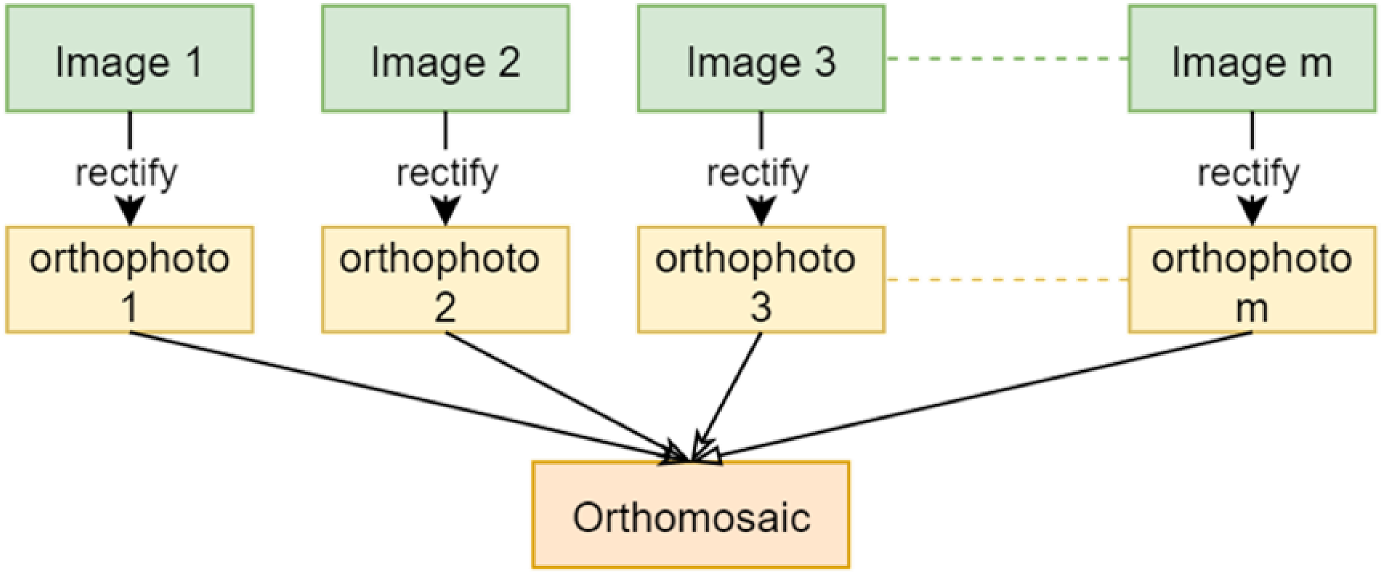
1. An image matrix with the same resolution as the image is created
2. The matrix is used to store **the distance (Z)** of each pixel between the object surface and the image.
3. Labeling the matrix pixel as visible if the ray is not interested by other features.
4. If output pixel whose ray intersects other visible features along the way from the DSM cell to the image is considered as an occluded pixel.



https://www.mdpi.com/2072-4292/10/4/581

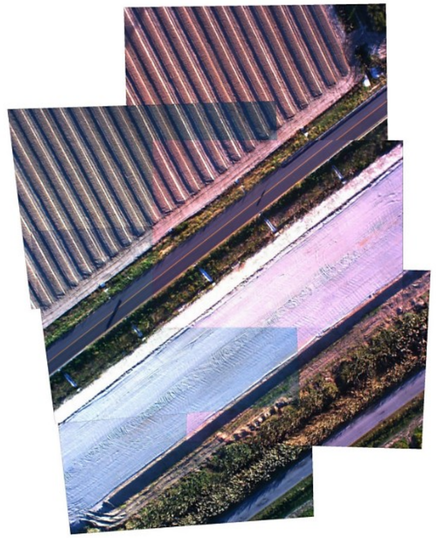
Orthomosaic

Orthomosaic is an orthorectified image product that has been mosaicked from a series of UAV images, with the geometric distortion removed and the imagery color-balanced to create a smooth mosaic dataset.



Colour correction in Orthomosaic

- Color correction describes the act of **altering the colors of multiple orthophotos to more aesthetically pleasing or accurate.**
- This is often accomplished by altering the image's levels of red, green, and blue as well as its overall brightness and contrast.
- Changes in lighting conditions, varied camera settings, and vignetting are some of the reasons why the seams of the mosaic are noticeable.
- Even when color correction and image alignment yield the best results, seams may still be seen on the mosaic as a result of things like moving objects.



before color correction

after color correction

Source https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/IV-2/247/2018/isprs-annals-IV-2-247-2018.pdf

Blending: examples

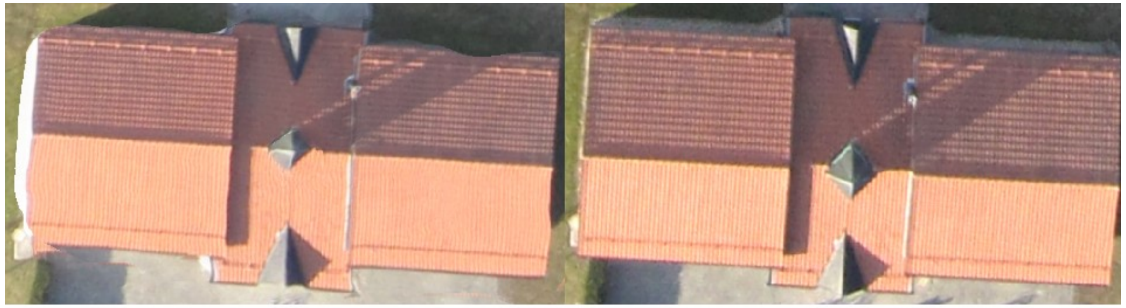
- Image blending is the technique of fusing several images into one image to produce a more smooth and attractive finished output.

Different blending methods ae found:

- **Feathering blending:** this is the simplest blending method. It uses a smooth transition from one image to another image to reduce the visibility of the seams.
- **Pyramid blending**: This method uses a multi-resolution pyramid representation of the images to create a seamless mosaic. The algorithm starts by blending the images at the lowest resolution, and then gradually increases the resolution until the final mosaic is obtained.

Orthomosaic Artifacts and Distortions

- Based on the DSM that is produced from the dense point cloud, the orthomosaic is produced. **Thus, the orthomosaic will represent any flaws and noise present in the dense point cloud**.
- The points' altitudes will not be precisely computed in the point cloud. For excellent datasets, errors and noise are always there but are minimized (high overlap, good visual content of the images, use of GCPs, etc.).
- Altitude disparities of points that belong to the same roof edge of a structure or the same edge of a bridge cause deformities on building edges, bridges, etc. in the Orthomosaic.



Orthomosaic before editing

Orthomosaic after editing using the Mosaic Editor

Source: https://support.pix4d.com/hc/en-us/articles/202561099-Distortions-and-Artifacts-in-the-Orthomosaic

Quality Assurance

- With respect to quality of orthomosaic we should consider:
  - **Image appearance (radiometric quality)**

    The image appearance depends largely on the **quality of the original image**, but also on **radiometric** enhancement.

Source: itc.nl

`Absolute Positional accuracy

Positional error measured as RMSE:

$$\sigma_p = (\sigma_X^2 + \sigma_Y^2)^{½};$$

$$\sigma_X = \sqrt{\frac{\sum (X_i - {}_C X_i)^2}{n}}$$

$$\sigma_Y = \sqrt{\frac{\sum (Y_i - {}_C Y_i)^2}{n}}$$

Point ID:	GCP 2
Location on Image (zoom in 1) *The point can be found in DJI_0162.jpg*	*Location image (zoom in2)*
	
Location in the field (picture 1)	*Location in the field (picture 2)*
	

Source: itc.nl

Pixel size for orthophoto

Digital Orthophotos in the computer can be at any scale and any size.

What is the suitable pixel size for digital image ?

- The orthophoto pixel size in units on the ground recommended not be smaller than the GSD of the original image!!! But can be the same.

Source: itc.nl

Applications

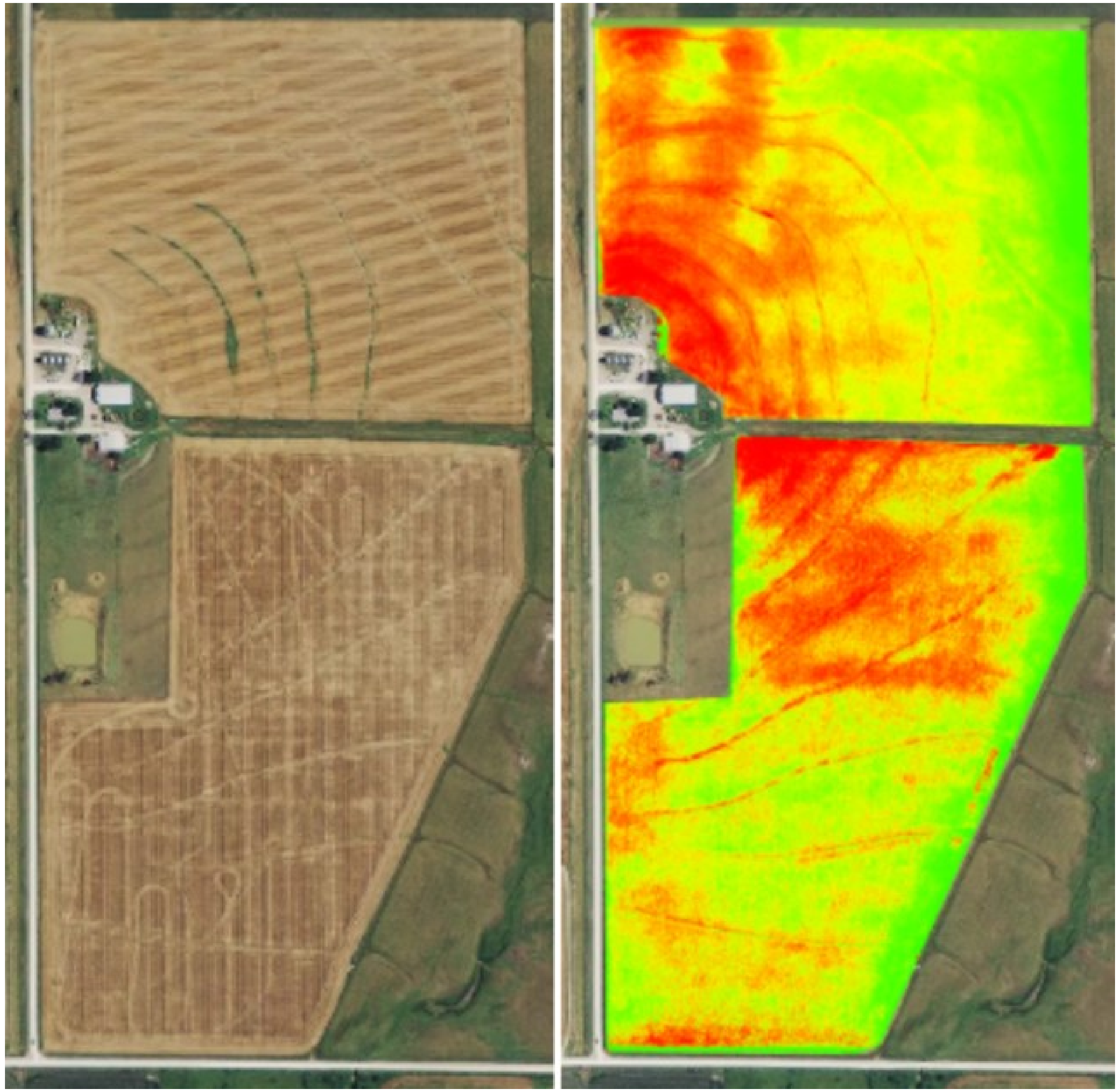
There are many applications for using the UAV orthomosaics like:

- Farming
- Law enforcement
- Real estate
- Environmental protection
- Construction
- Disaster management
- Urban planning
- Mining

Etc.

UAV Orthomosaic for Farming

- UAVs' high-resolution orthomosaic may provide farmers a thorough perspective of their crops and help them make more educated crop management decisions.
- UAV orthomosaics monitor crop growth, spot stressed/diseased regions, aid early detection for farmers.
- Crop plants and trees may be counted and mapped using UAV orthomosaics, which is helpful for calculating yields, preparing for harvest, and monitoring crop progress.
- UAV orthomosaics can be used to track irrigation systems, spot regions that are flooded, or measure the moisture content of the soil.



Source: https://botlink.com/

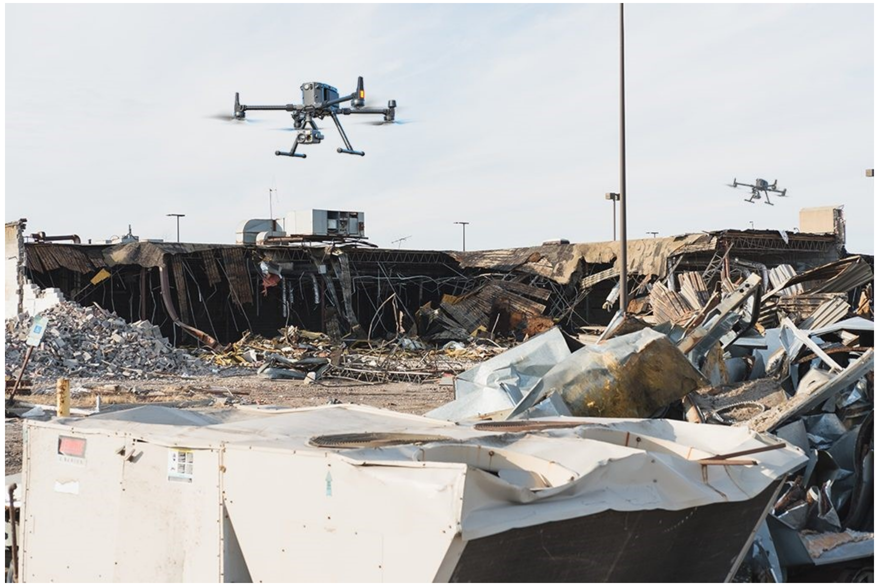
UAV Orthomosaic for Disaster response

- In order to determine the amount of the damage, identify the most affected places, and organize rescue and recovery operations, orthomosaics might be employed.

- By having UAV orthomosaics of the area before the disaster, it can be compared to the after-disaster images and can provide an accurate view of the changes occurred in the area.

- Orthomosaic used to plan for rescue and recovery efforts, and to identify areas that need the most urgent attention.

- UAV orthomosaics may also be incredibly helpful when reacting to wildfire events since they can give specific details about the size and intensity of the fire and help with the organization of firefighting activities.



Source: https://www.flytnow.com/

UAV Orthomosaic for civil engineering

Many useful applications of using UAV orthomosaics in road management like:

Surface condition assessment , Drainage inspection, Bridge and culvert inspection, Volume calculation, and Progress monitoring, else

- The amount of materials on site, such as the volume of earthworks, stockpiles, and cuttings, may be calculated using UAV orthomosaics, giving crucial information for cost and planning purposes.
- Progress monitoring: By comparing the images captured at various phases of a project, UAV orthomosaics may be used to track the progress of building projects, giving crucial information for budget, planning, and quality control.

Source: https://feds.ae/construction-made-efficient-with-drone-progress-monitoring/

Thank you