Introduction to Photogrammetry

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- Drones for mapping how it works
- Cameras
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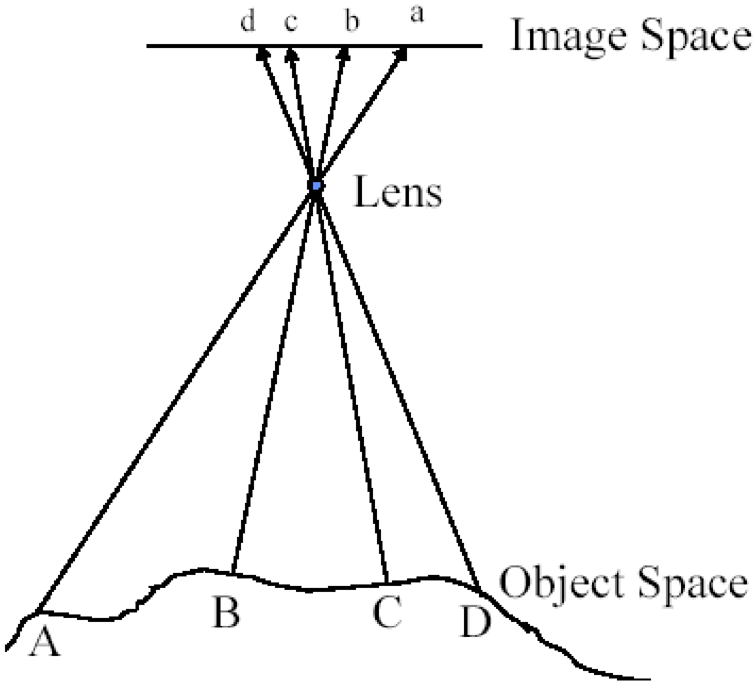
  - Elements of camera
  - Lens distortions
  - Illuminance, Aperture and Depth of field
- Images
- Photogrammetric processing
- Flight planning
- Photogrammetric GCPs

Photogrammetry

Photo - light
gramma - something drawn
metrein - measure



Photogrammetry = measuring with photographs

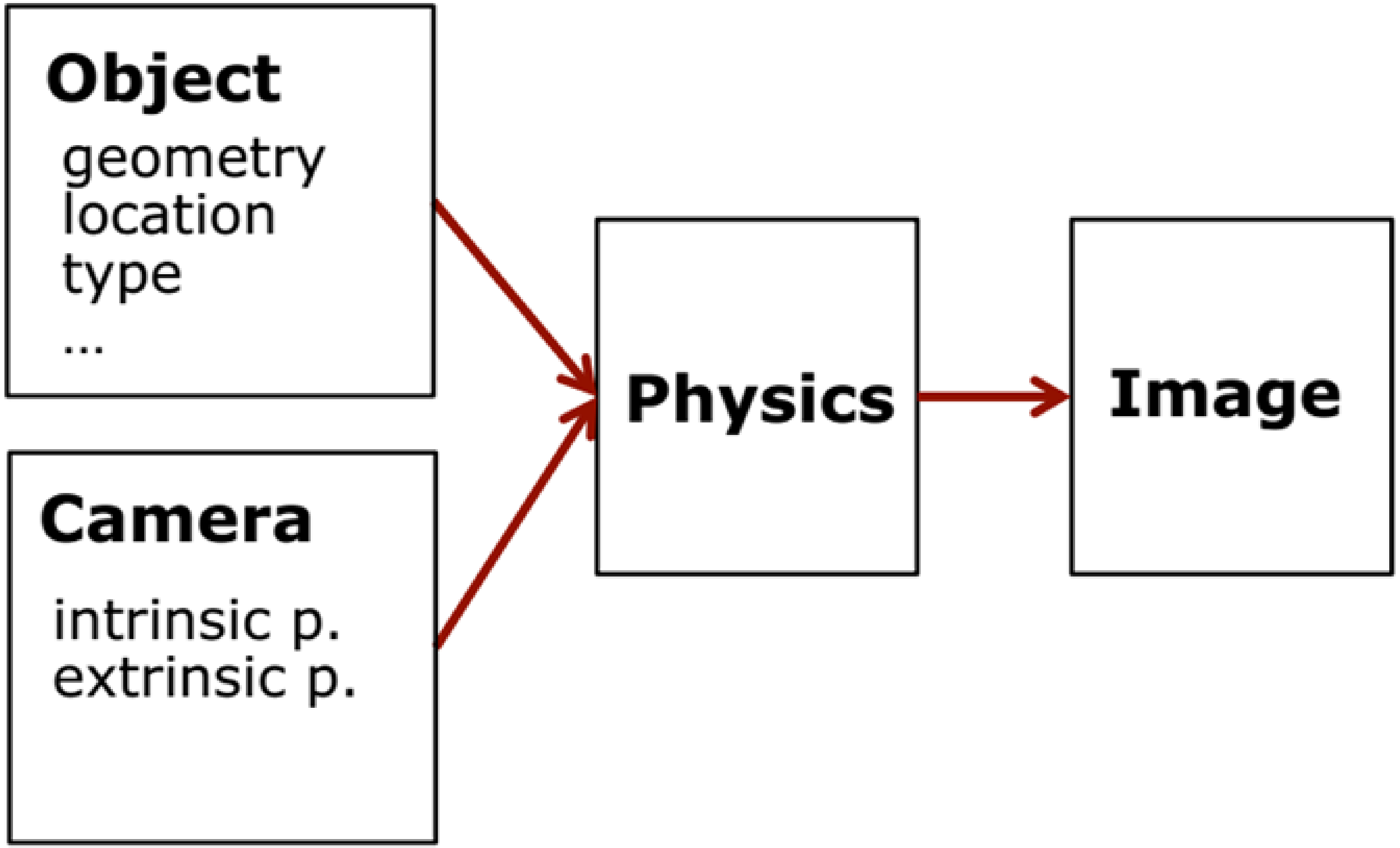
Objective is…

Inverse the process of photography (i.e. reconstruction of the object space from image space).

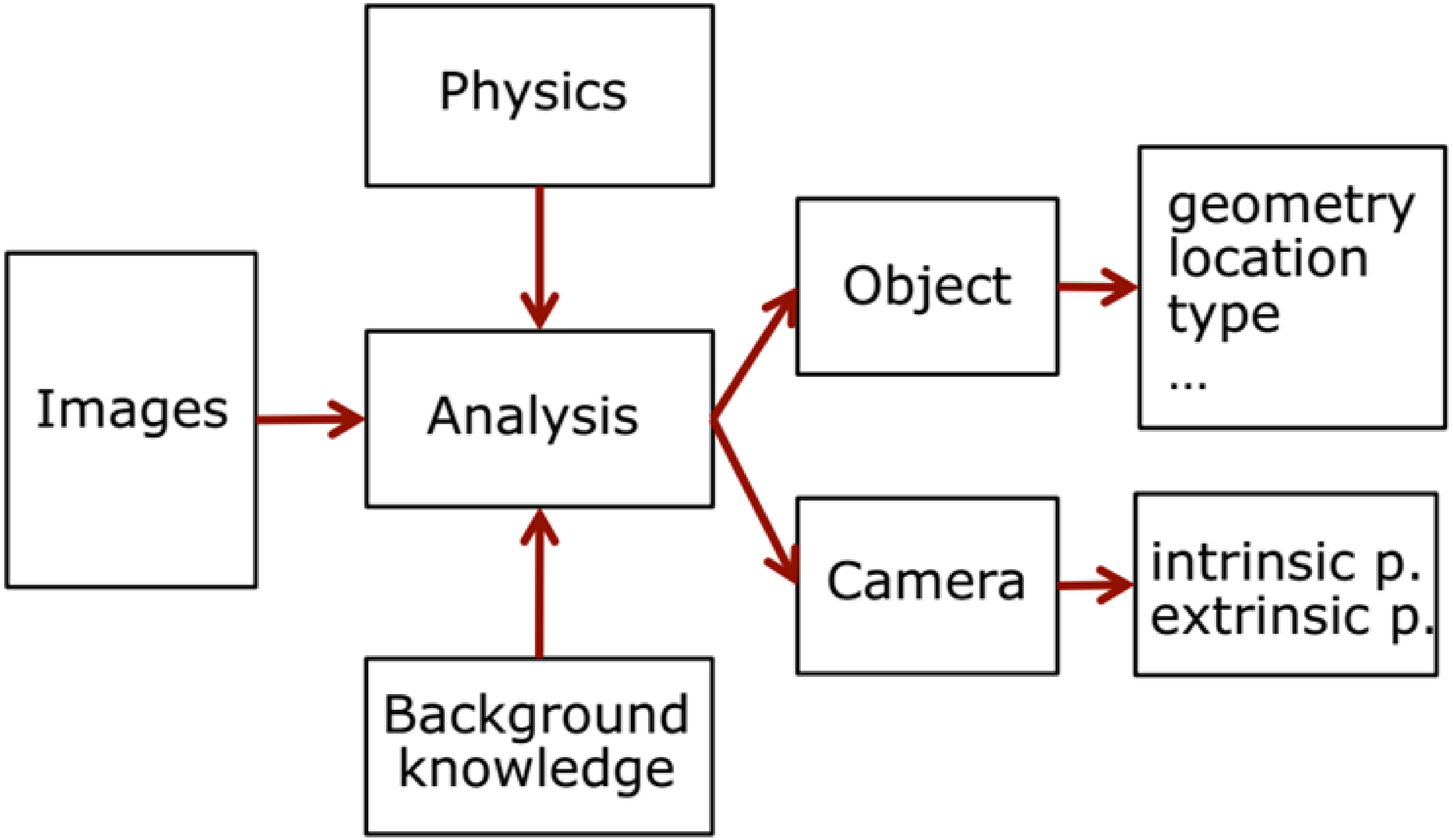
Results can be,

- ***Topographical/Planimetric/Thematic maps***
- Coordinates of the required object points
- Rectified Photos

From Object to Image

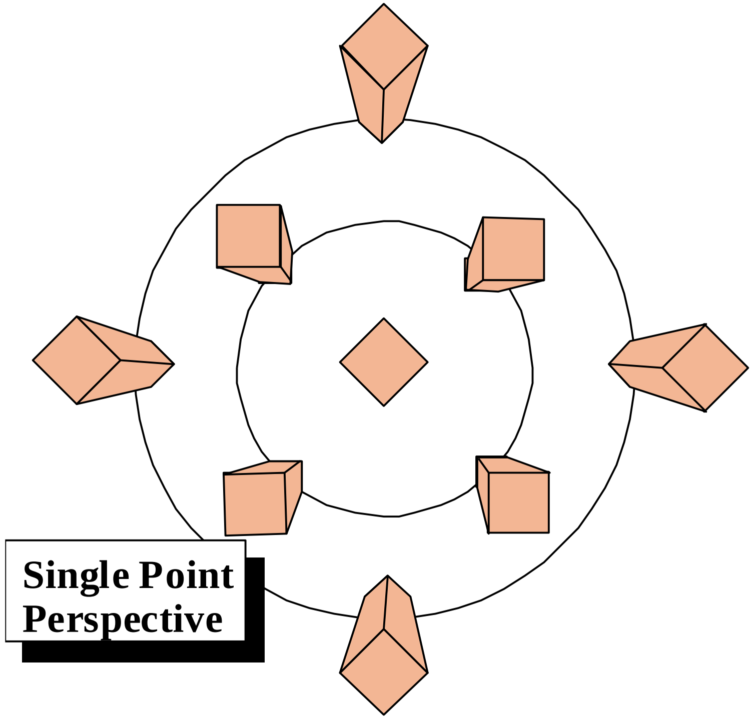


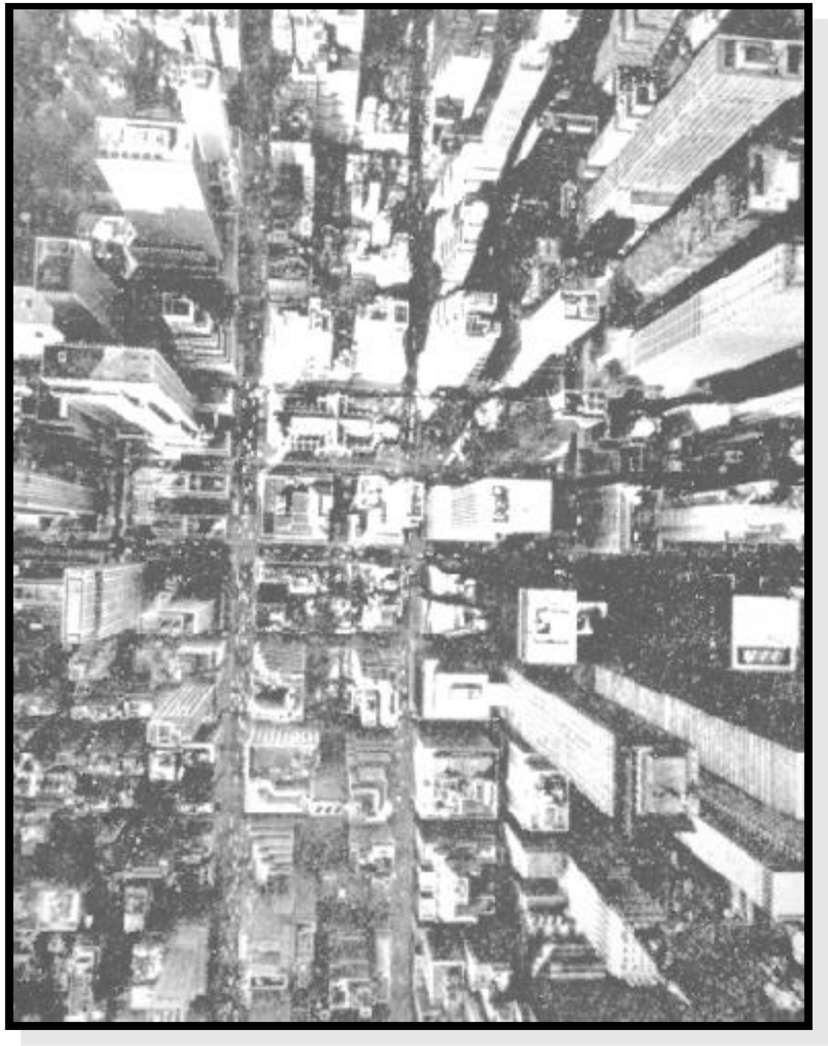
Inverted Mapping



2D → 3D Why?

Can you used aerial photograph as a map directly?





The photo scale is different at the tops of the buildings than at the street level. The tops of the building are displaced radially outward relative to their location at the center.

2D → 3D Why?

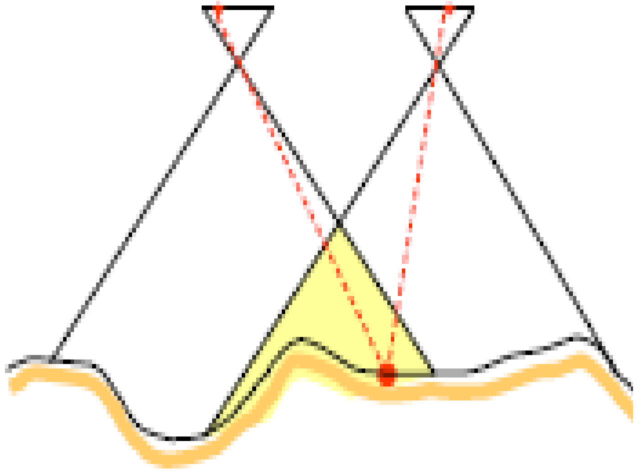
Can you used aerial photograph as a map directly?

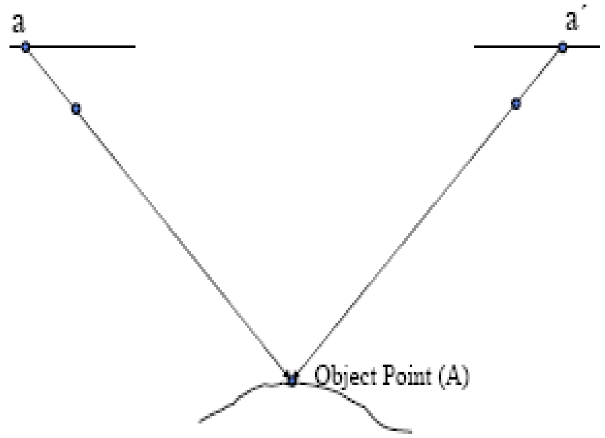
2D → 3D Why?

Can you used aerial photograph as a map directly?

Relief Displacement

How to prepare maps from Aerial Photographs?





3D

Real World

Central Projection →

Aerial Photo -2D

↓

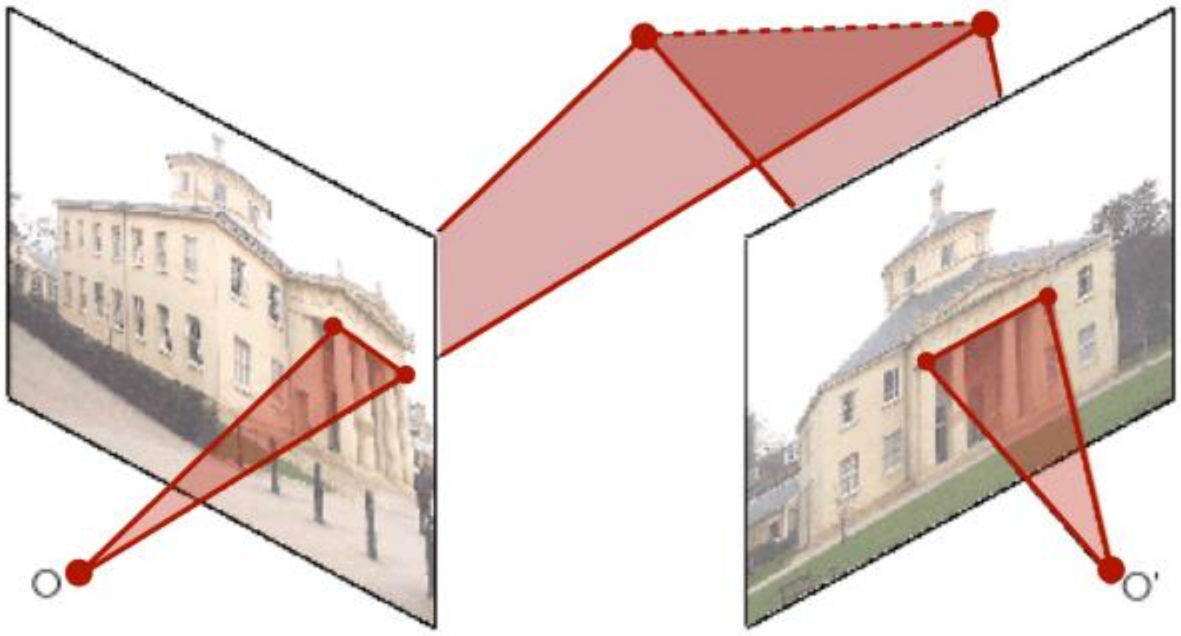
Ground Model -3D

← Orthogonal Projection

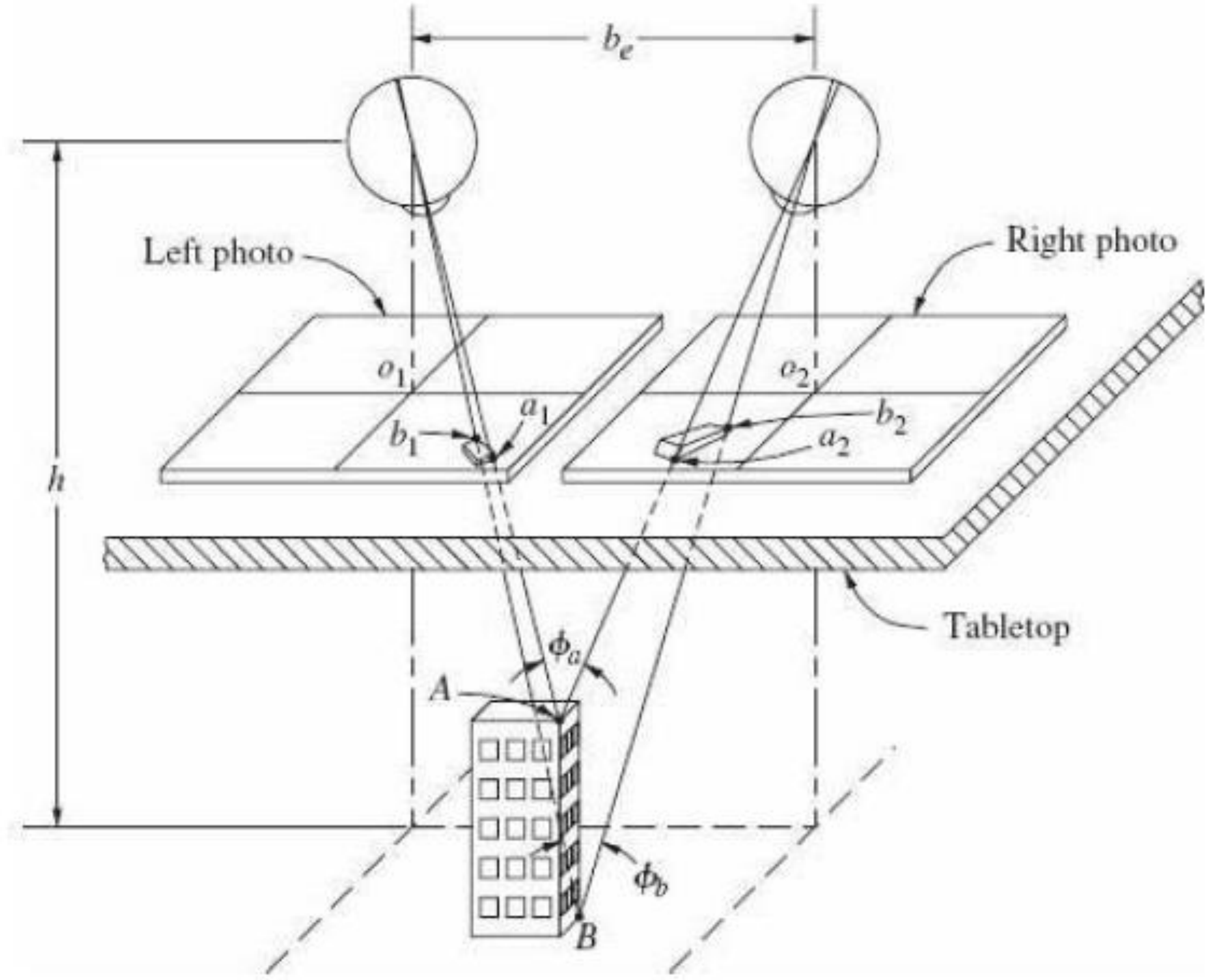
Map -2D

2D → 3D

Multiple observations from different directions allows for estimating the 3D location of points via triangulation

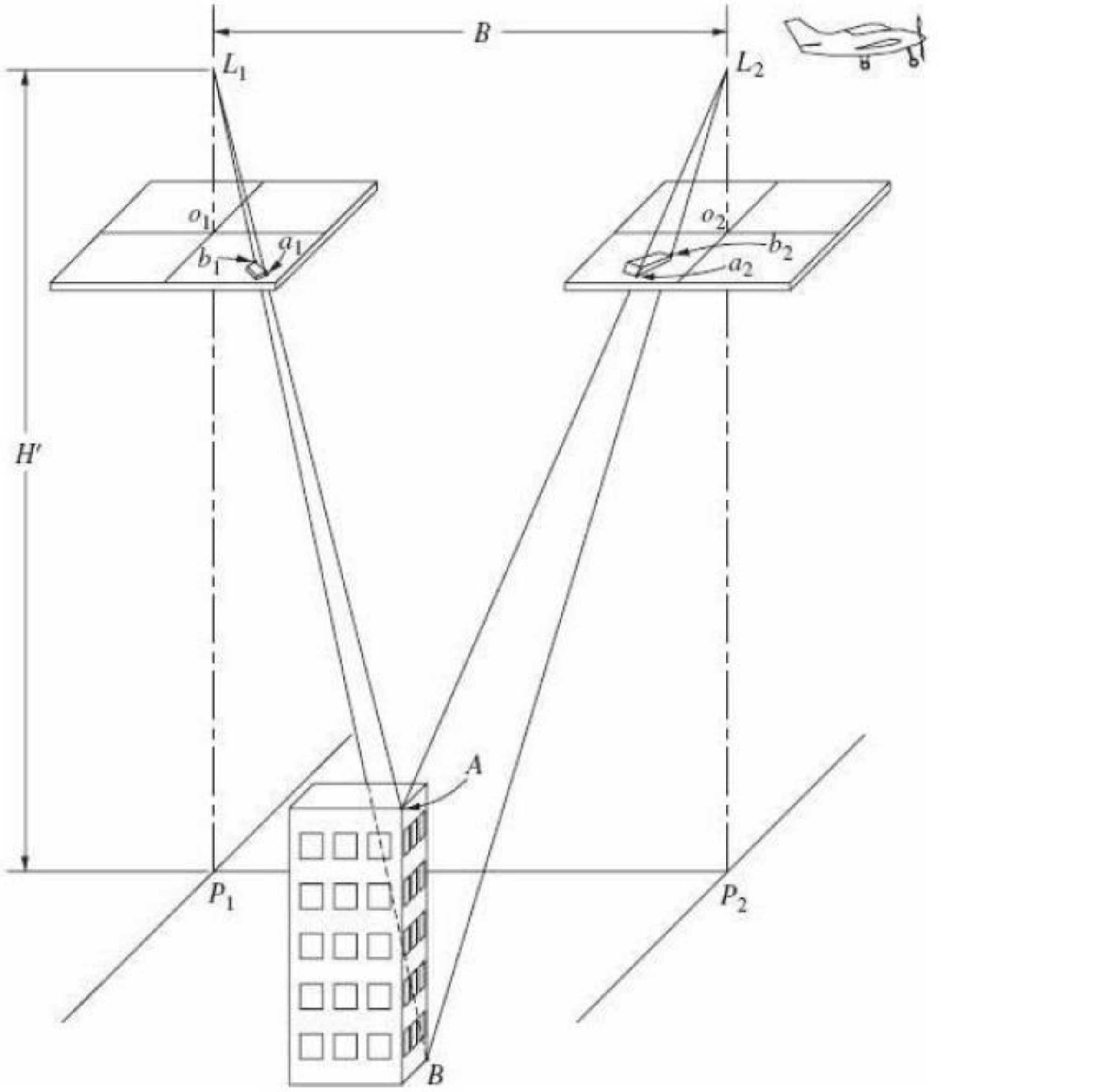


2D → 3D

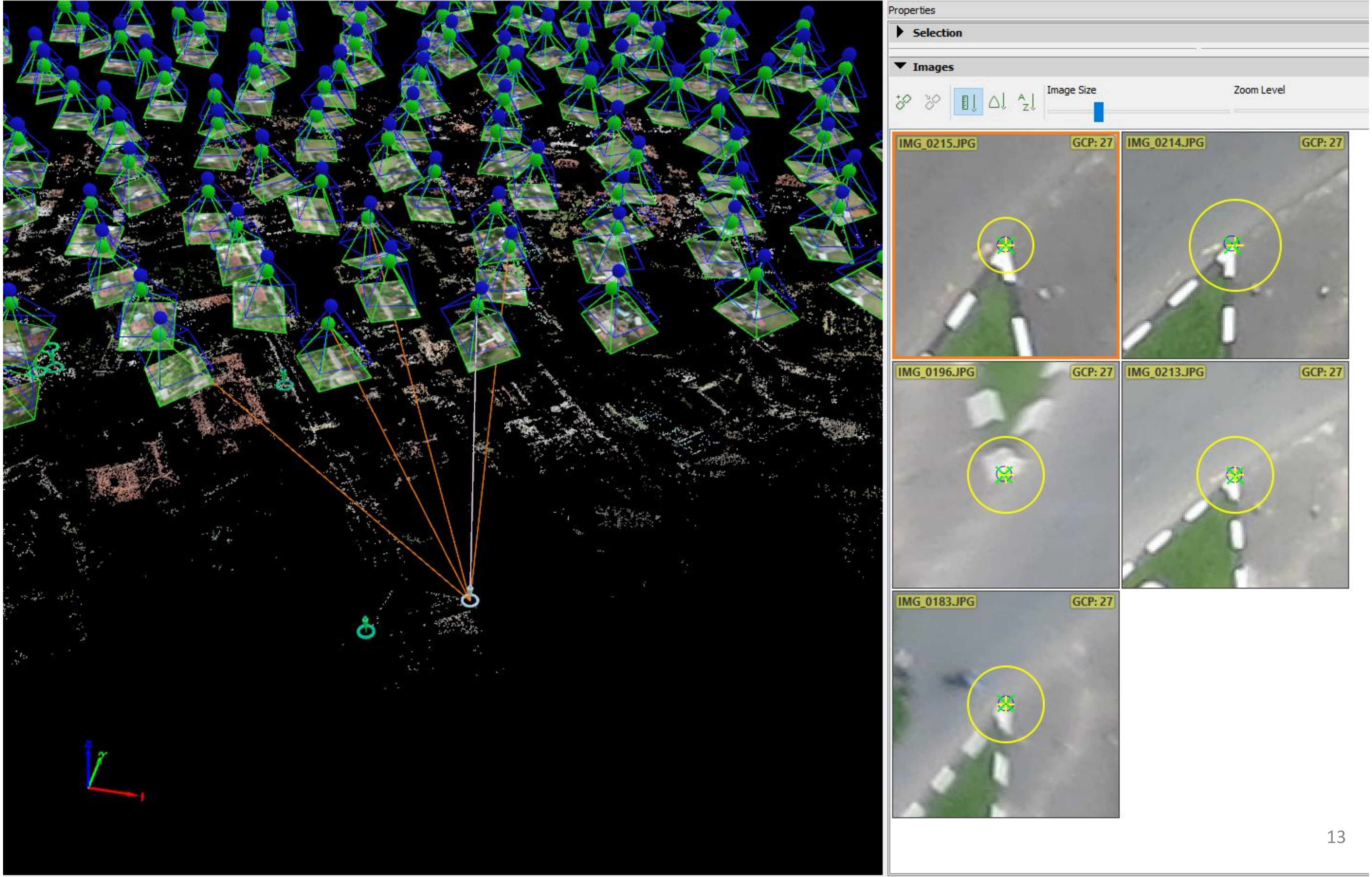


Viewing the building stereoscopically.

2D → 3D



Photographs from two exposure stations with building in common overlap area.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Images
Image Size
Zoom Level
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GCP: 27
IMG_0214.JPG
GCP: 27
IMG_0196.JPG
GCP: 27
IMG_0213.JPG
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IMG_0183.JPG
GCP: 27

2D → 3D

Map 2D to 3D Only With Photographs taken from Calibrated/Non Calibrated Camera

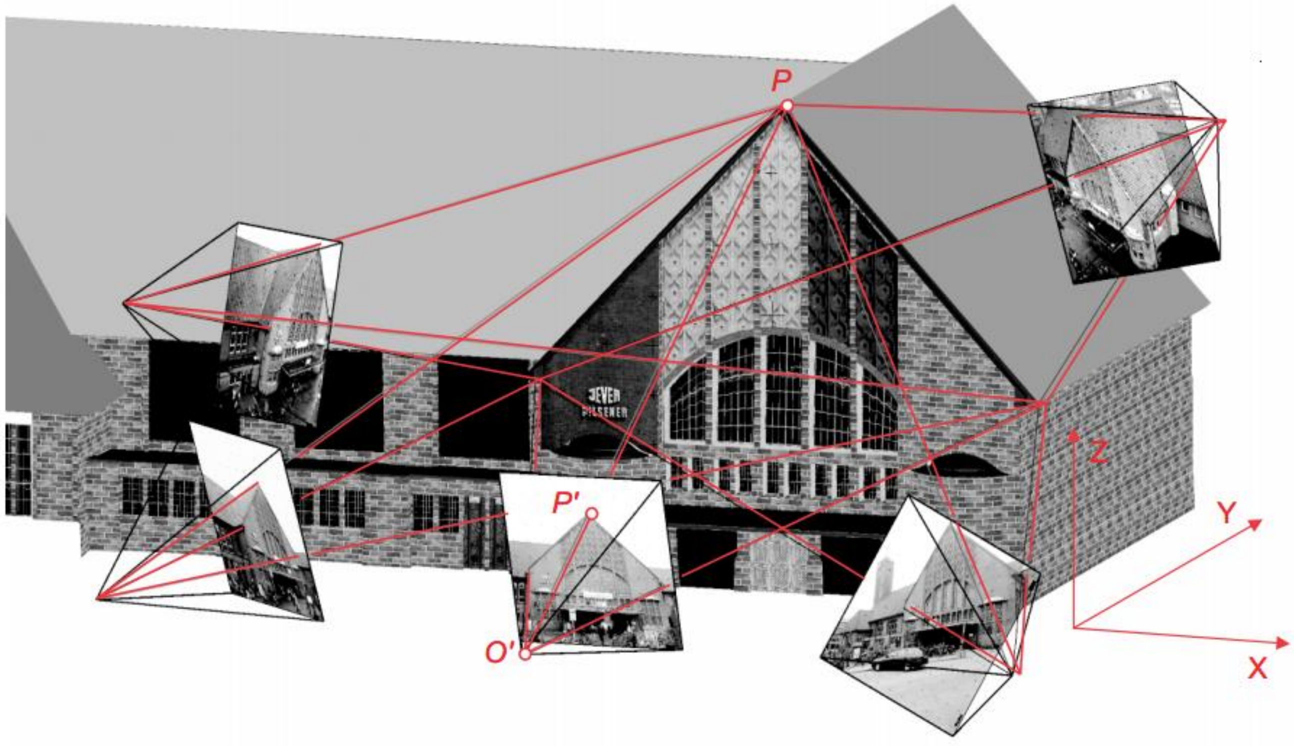


Photo Coordinates (2D) = Projection Matrix x World Coordinates (3D)

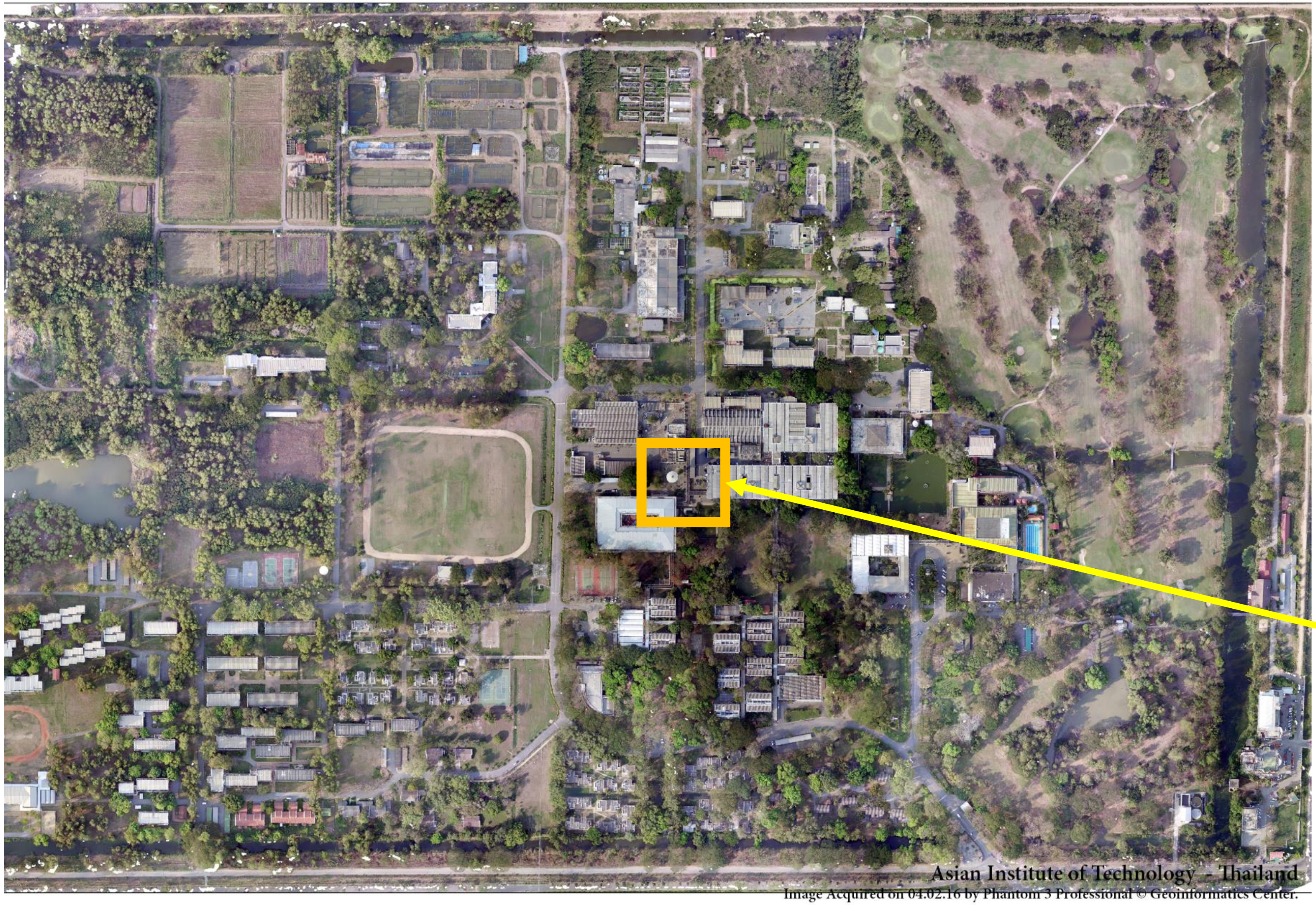
$$\mathbf{x} = \mathrm{P}\mathbf{X}$$

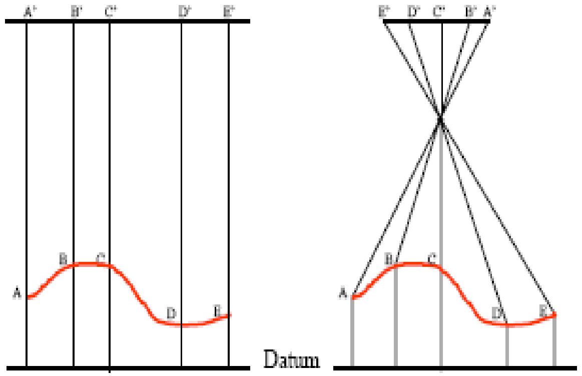
$$\mathrm{P} = \begin{bmatrix} \alpha_x & s & p_x \\ & \alpha_x & p_y \\ & & 1 \end{bmatrix} \begin{bmatrix} \mathrm{R} & -\mathrm{R}\tilde{\mathrm{C}} \\ 0 & 1 \end{bmatrix}$$

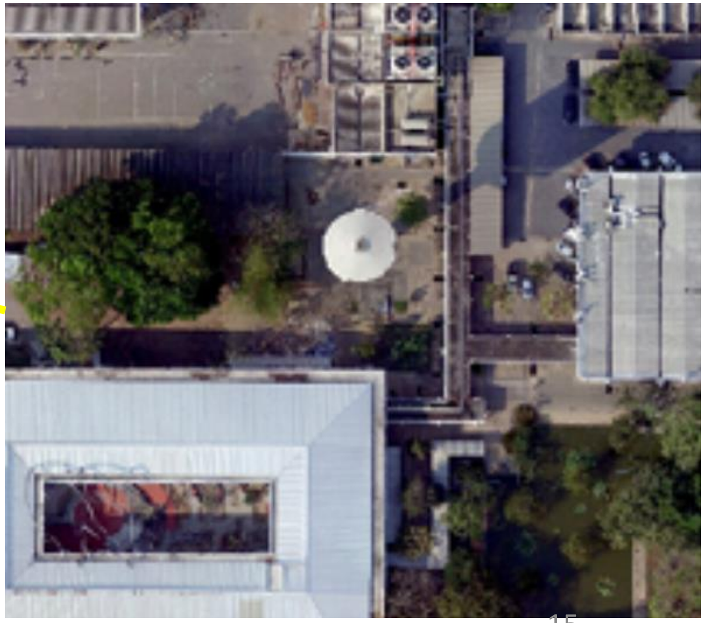
Camera Matrix

Projection Matrix (P) 11 DOF

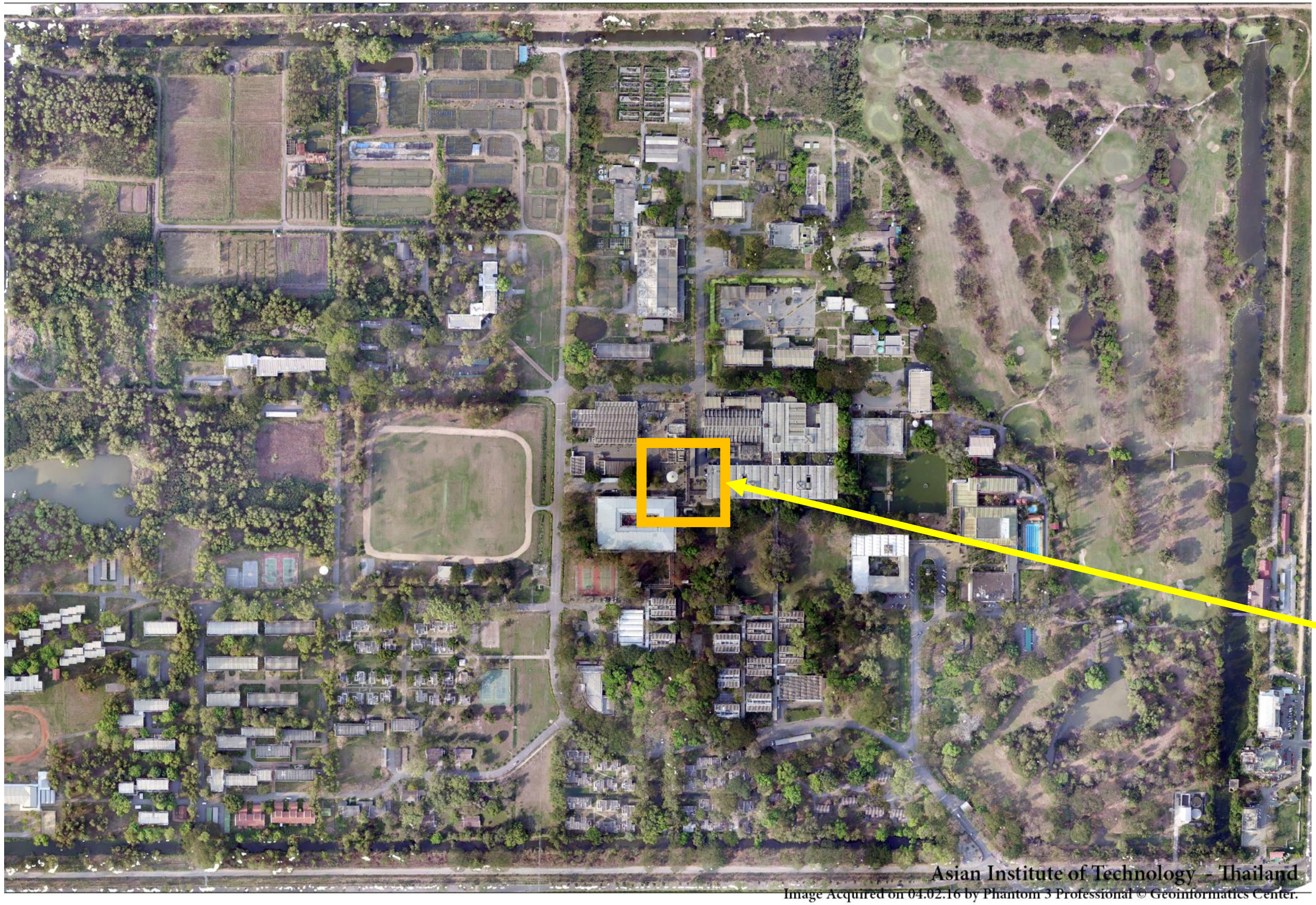
Orthoimages



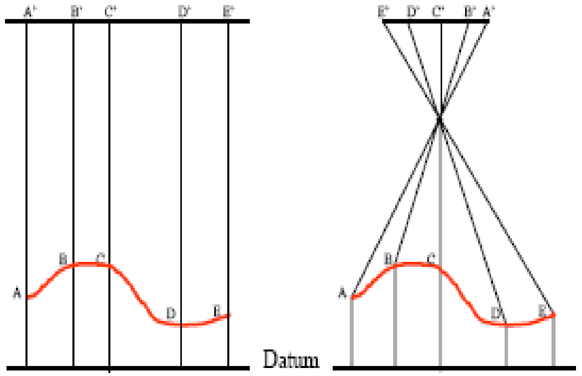


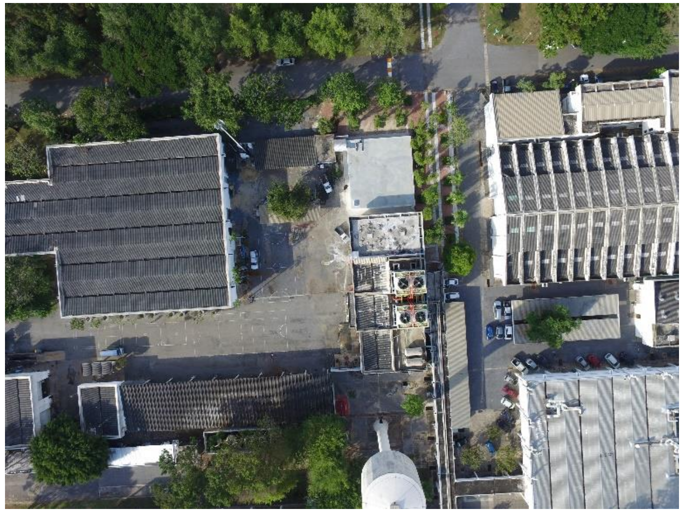


Orthoimages



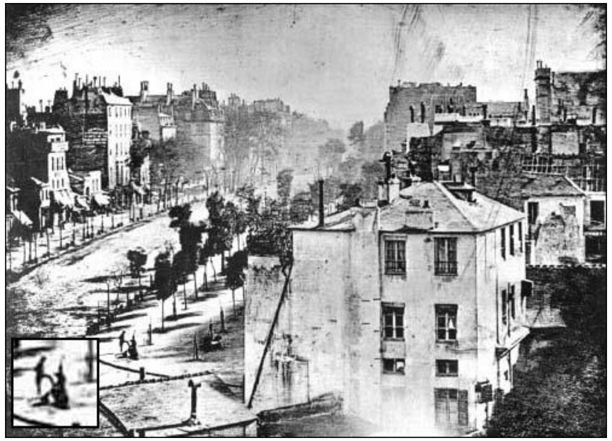
Orthogonal versus Central Projection





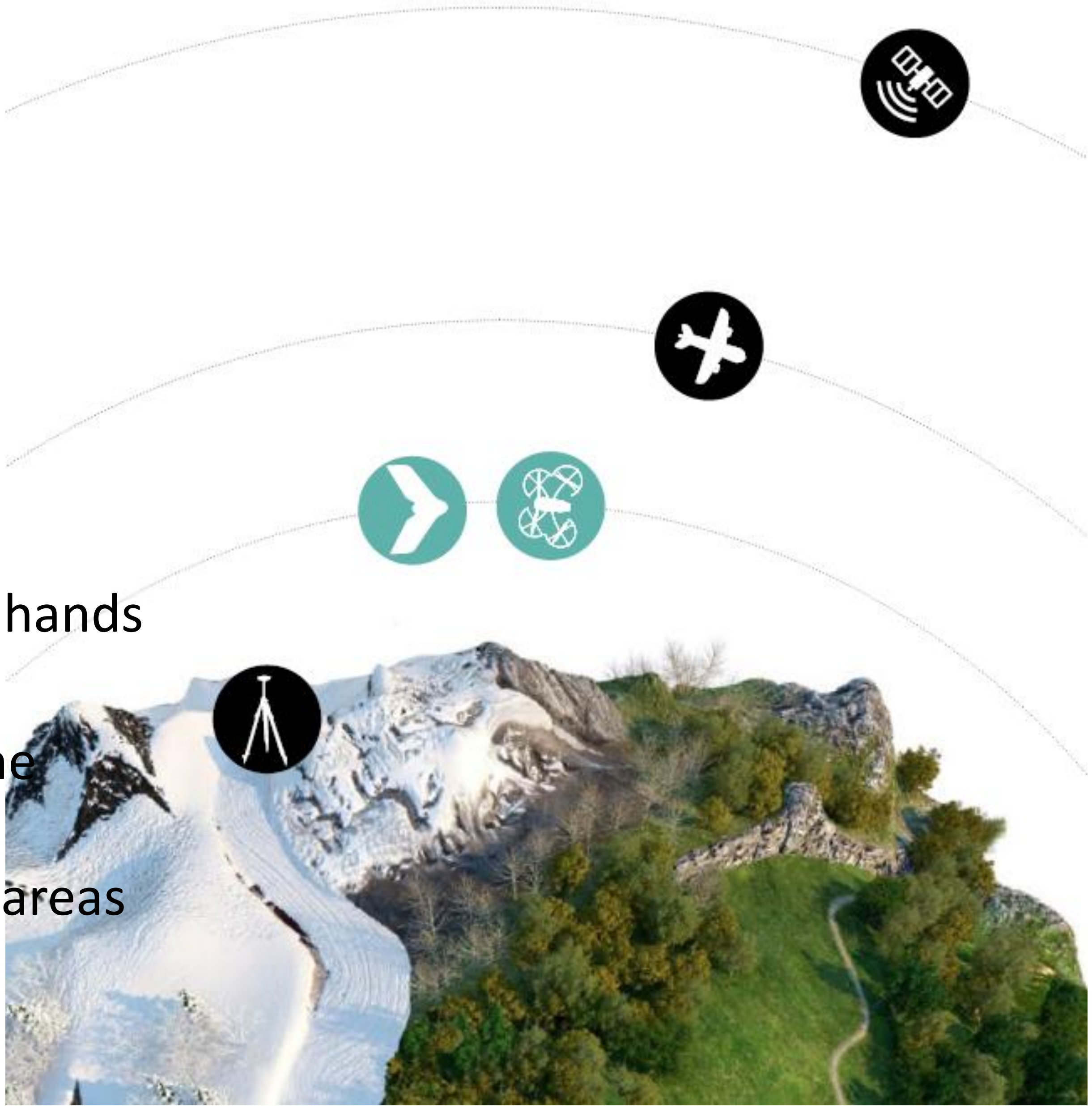
Why Photogrammetry?

Evolution of Photogrammetry



UAVs in Mapping

- Main Benefits
  - **Economical** - up to 90% compared to traditional methods
  - **Easy to Fly** - Ready to go system with automated flight planning
  - **Accuracy** - High accurate products
  - Very high resolution areal imagery in your hands
  - Millions of data points in one short flight
  - **Timescale** - Comparatively reduce the time spent collecting accurate data.
  - Operational in hazardous & hard-to-reach areas



Survey Grade Drones vs Consumer Grade Drones

Specifically Designed for Mapping	Designed for Consumer Applications - Photography, Hobby
Expensive	Less expensive
Not much popular (yet)	Very popular among the community
Need specific knowledge to operate	Simple operation
Equipped with GNSS and IMU	Equipped with GNSS and IMU
Able to perform high accurate 3D mapping	Has great potential to use in mapping

Trimble UX5

senseFly eBee

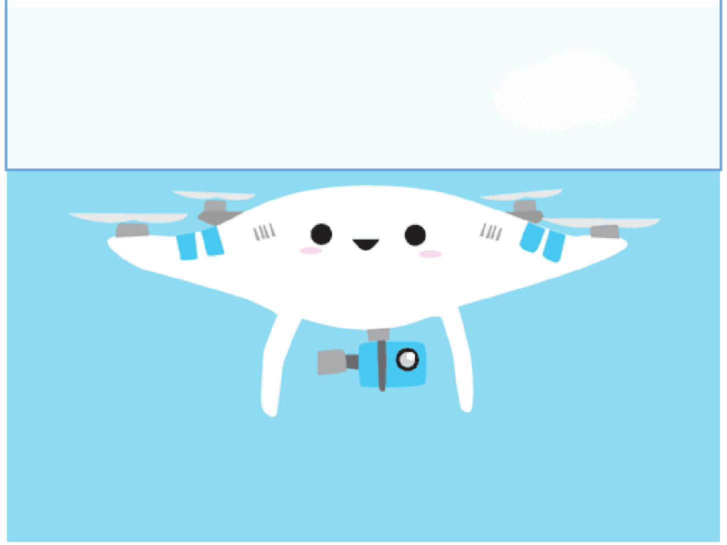
DJI Phantom 3

DJI Phantom 4

Parrot BeBop

Drones for Mapping – How it Works

Drone	Camera	Algorithm
• Platform to carry imaging sensor through accurate flight path.	• Captures overlapping images while in motion	• Computer Vision + Photogrammetry • Extracts geometry through matches of thousands of key-points for generating accurate maps and 3D models.



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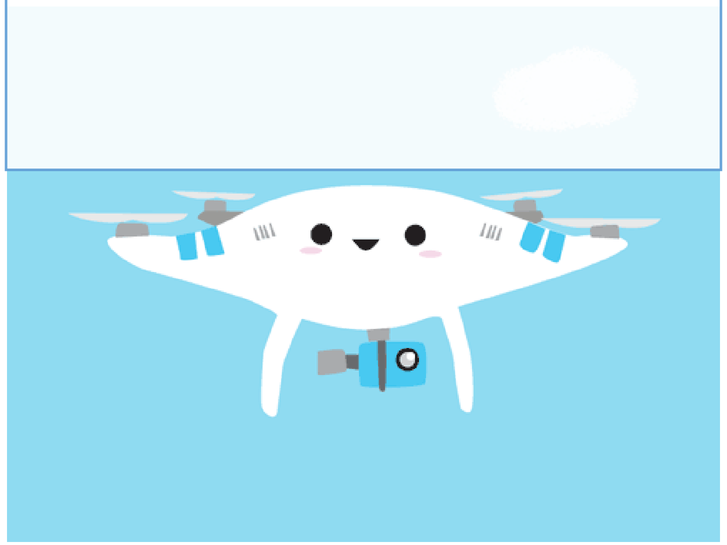
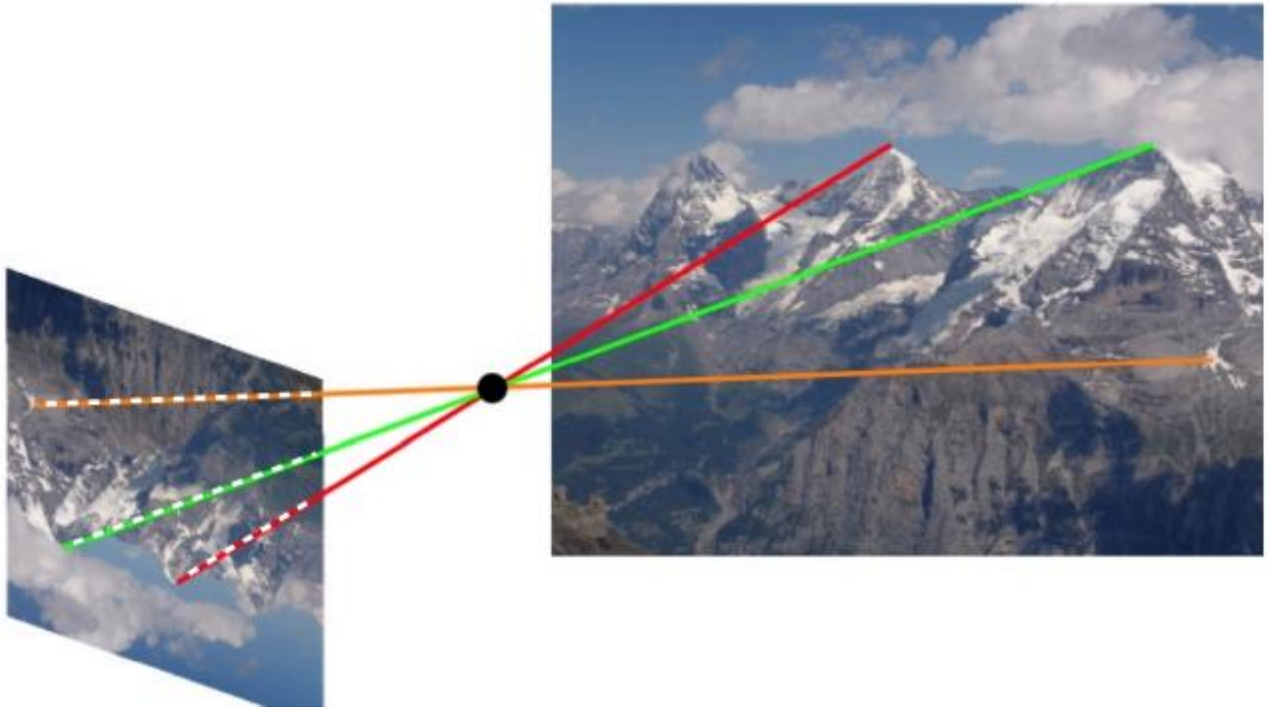


Camera

- The most fundamental device in the field of photogrammetry
- *what is a camera?*
  - “A lightproof chamber or box in which the image of an exterior object is projected upon a sensitized plate or film, through an opening usually equipped with a lens or lenses, shutter, and variable aperture.” *Manual of Photogrammetry*
  - “A camera is an optical instrument for recording or capturing images, which may be stored locally, transmitted to another location, or both.” Wiki

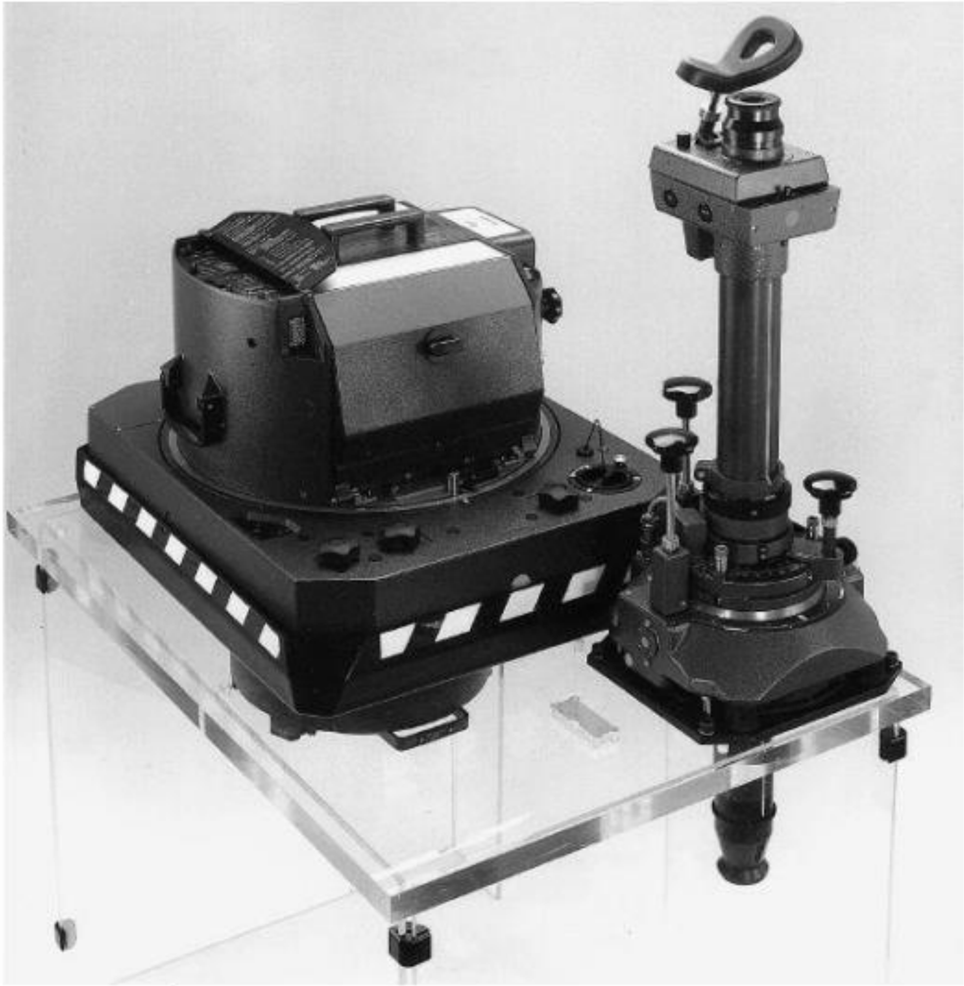
Cameras to Measure Directions

An image point in a camera image defines a ray to the object point



Consumer Cameras

Aerial Mapping Cameras

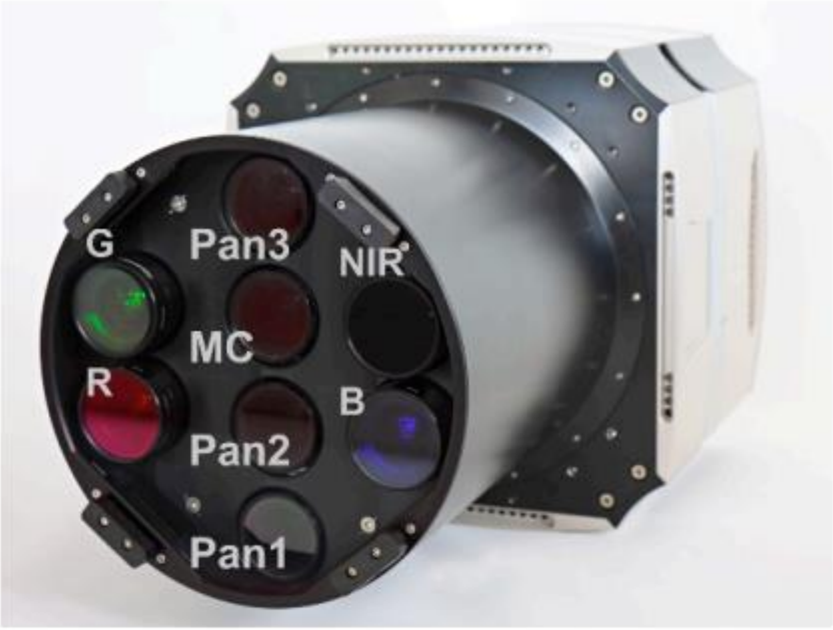


Leica RC30 aerial mapping camera. (*Courtesy LH Systems, LLC.*)

Z/I DMC II-250 digital mapping camera. (*Courtesy Z/I Imaging*)

Aerial Mapping Cameras

- Microsoft Ultracam (Bing Maps)



Cameras for Drones

- Consumer grade cameras
  - Point and shoot cameras
  - Mirrorless cameras
  - DSLR (heavy payload; not much conventional)

Sony WX – Default camera for eBee

Sony A6000

Canon EOS 5D

Cameras for Drones

- Cameras Designed for Drones
  - DJI FC300X – default with phantom 3 professional (built in)

Cameras for Drones

- Cameras Designed for Drones

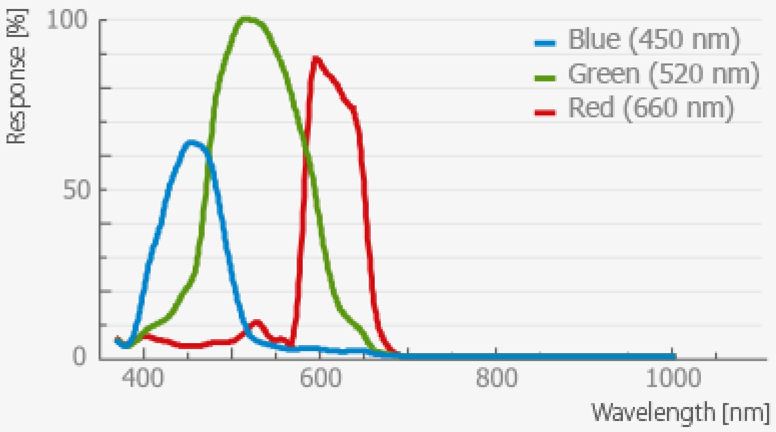
senseFly S.O.D.A.

The senseFly S.O.D.A. is the first camera to be designed for professional drone photogrammetry. It captures amazingly sharp aerial RGB images, across a range of light conditions, allowing you to produce detailed, vivid orthomosaics and highly precise digital surface models.
Video

High resolution RGB images

The 20 MP senseFly S.O.D.A. acquires regular image data in the visible spectrum. Its exposure parameters can be set manually within eMotion 3 and it can also output raw format (DNG) image files. The senseFly S.O.D.A. also includes built in sand & dust protection for use in the most demanding locations.

Band responses



Technical features

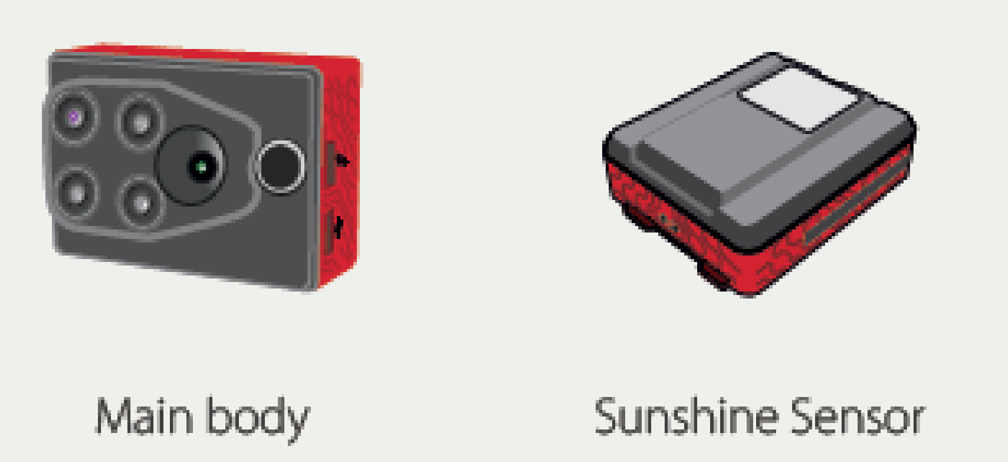
Resolution	20 MP
Ground resolution at 100 m	2.3 cm/px
Sensor size	12.75 x 8.5 mm (1-inch)
Pixel pitch	2.33 um
Image format	JPEG and/or DNG
Upward looking irradiance sensor	No

Characteristics

High wind & low light conditions	★★★★★
Usability	★★★★★
Mission flight time	★★★★★
Optimised aerodynamic profile	★★★★★
Orthomosaic & DSM	★★★★★
Ground Sampling Distance (GSD)	★★★★★
Band precision	★★★★

Cameras for Drones

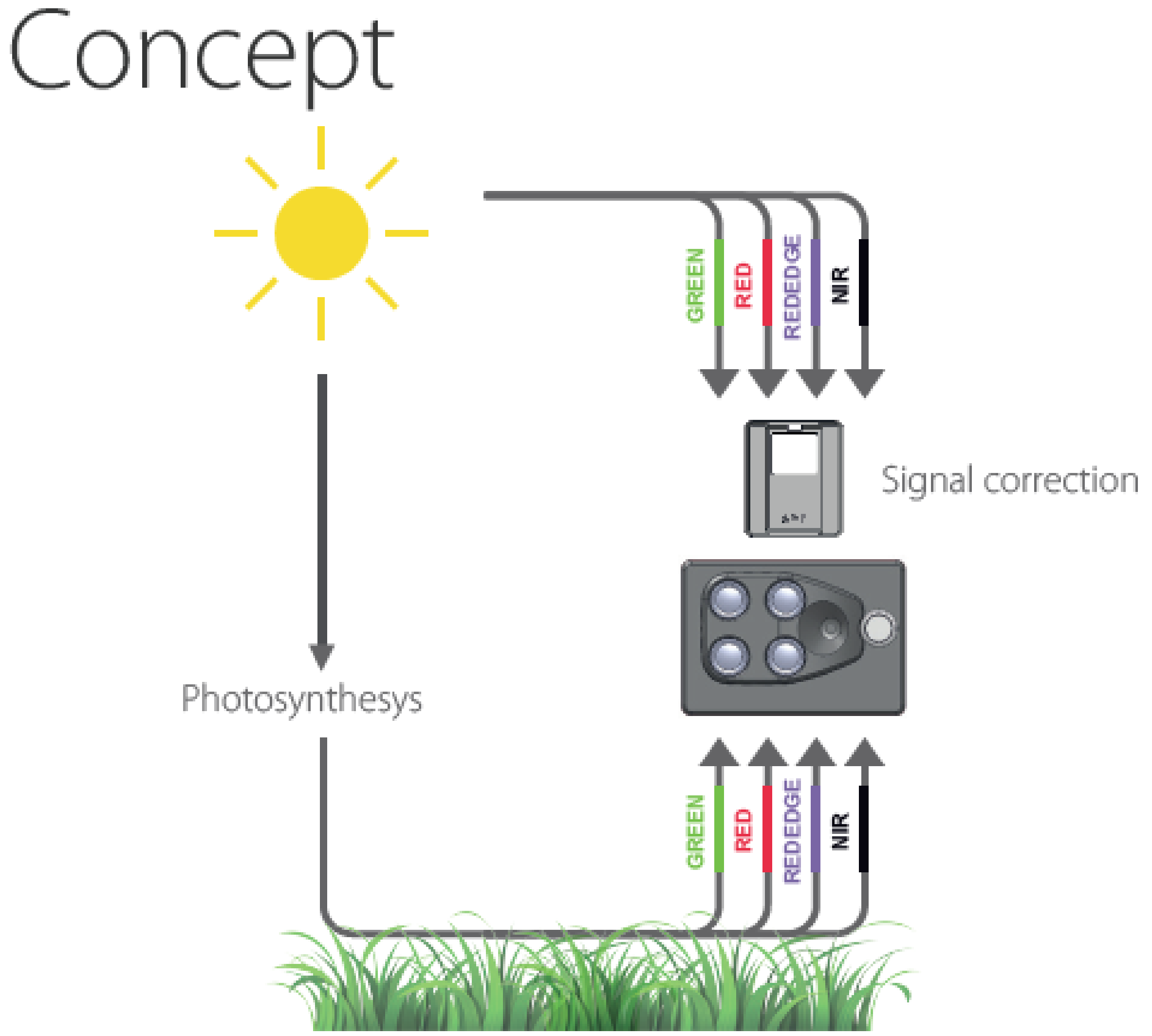
- Parrot Sequoia



- https://www.sensefly.com/fileadmin/user_upload/sensefly/documents/brochures/Sequoia_Specifications_2016_sensefly.pdf

Cameras for Drones

- Parrot Sequoia



Cameras for Drones

- Parrot Sequoia

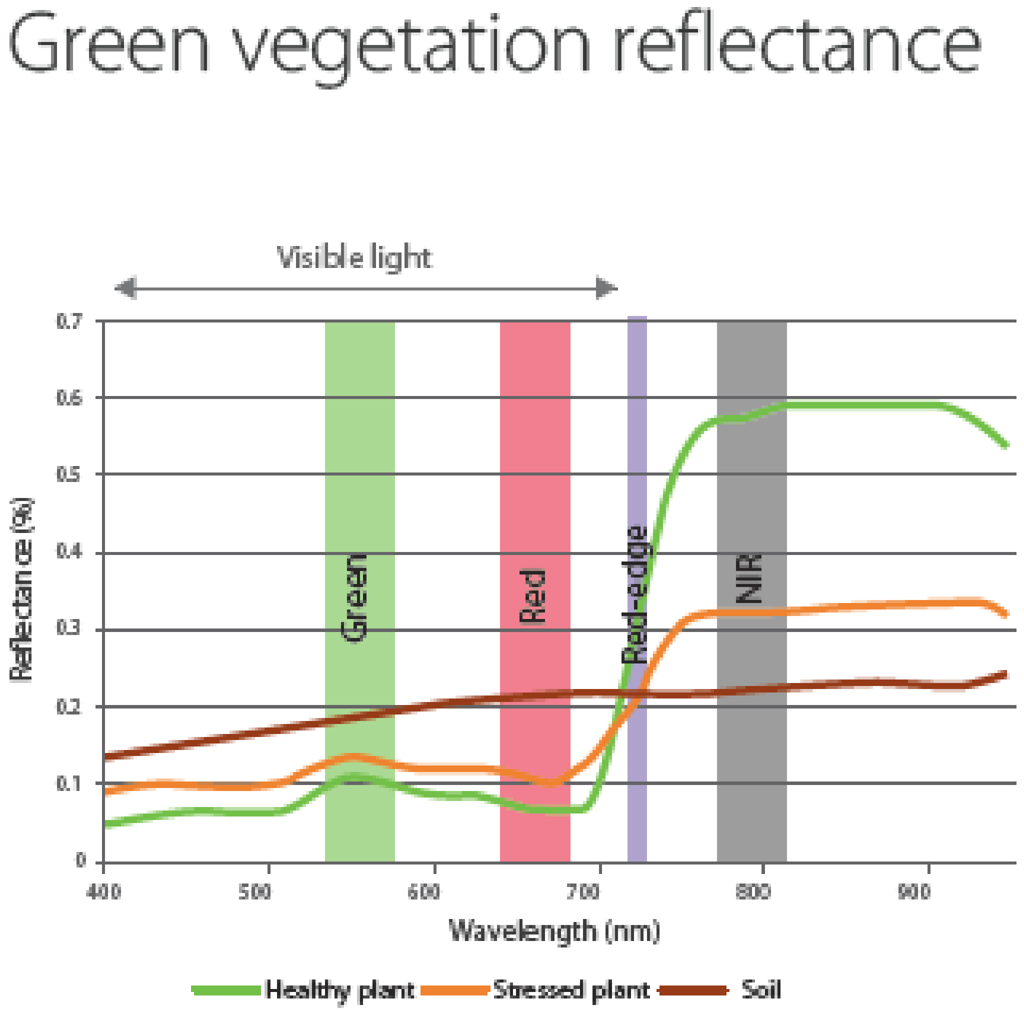


Image Formation

- Put a piece of film in front of an object
- Do we get a reasonable image?

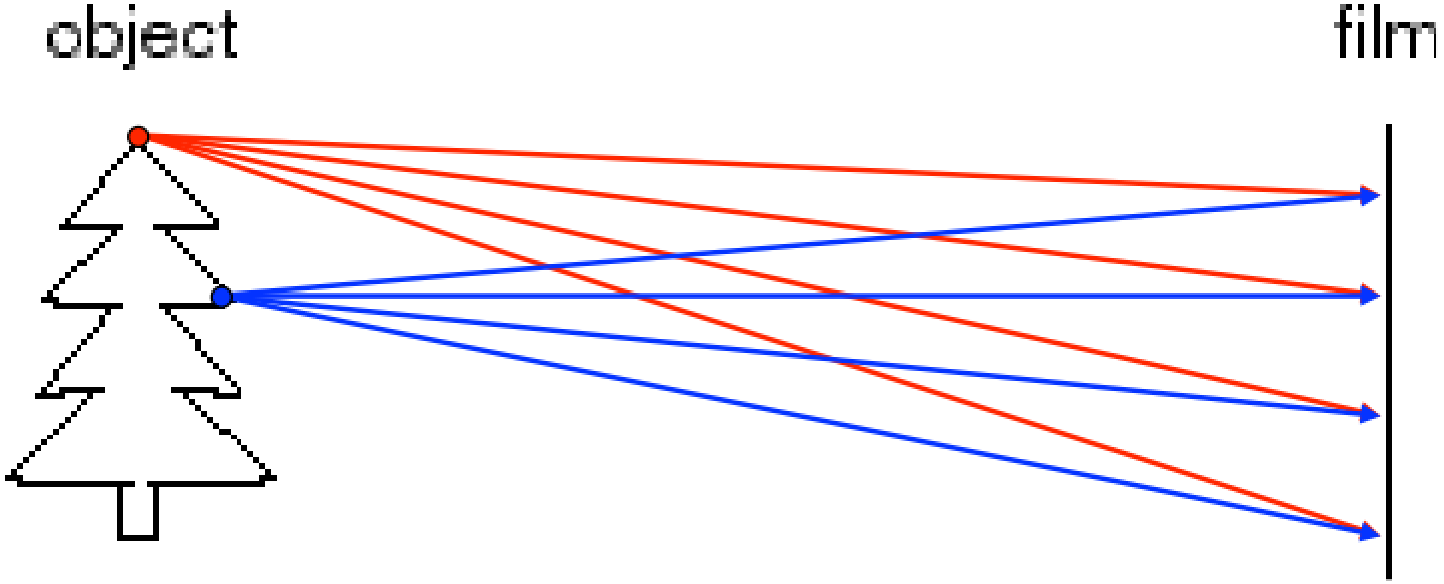
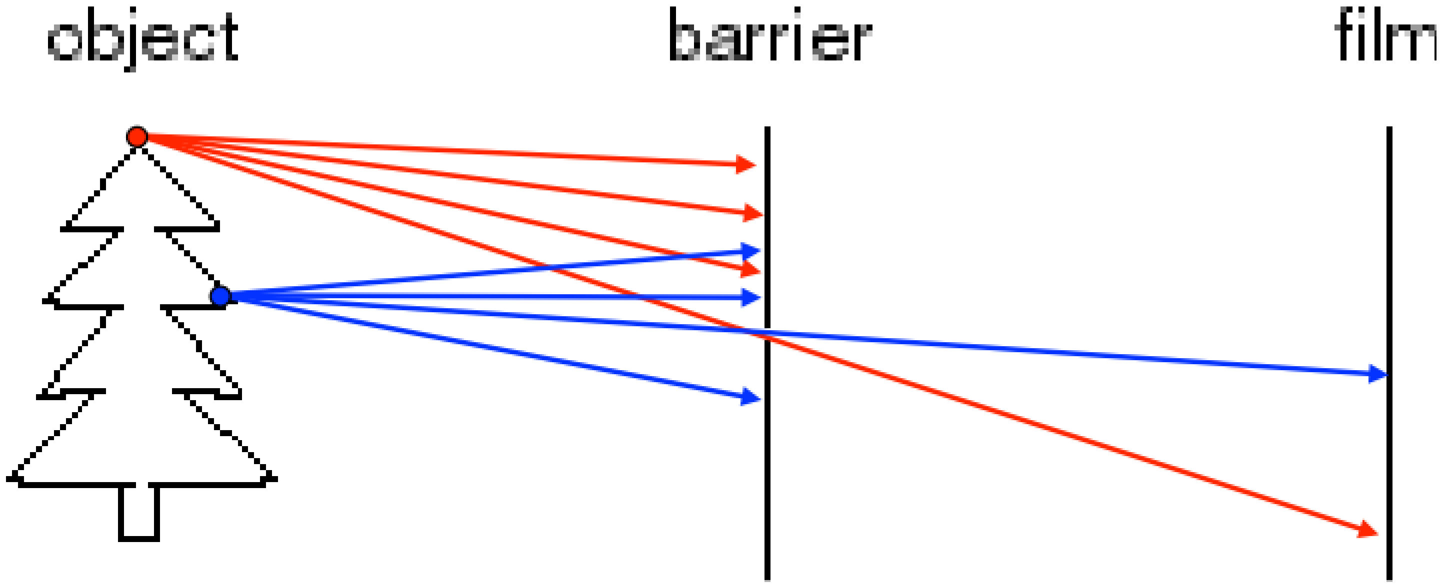


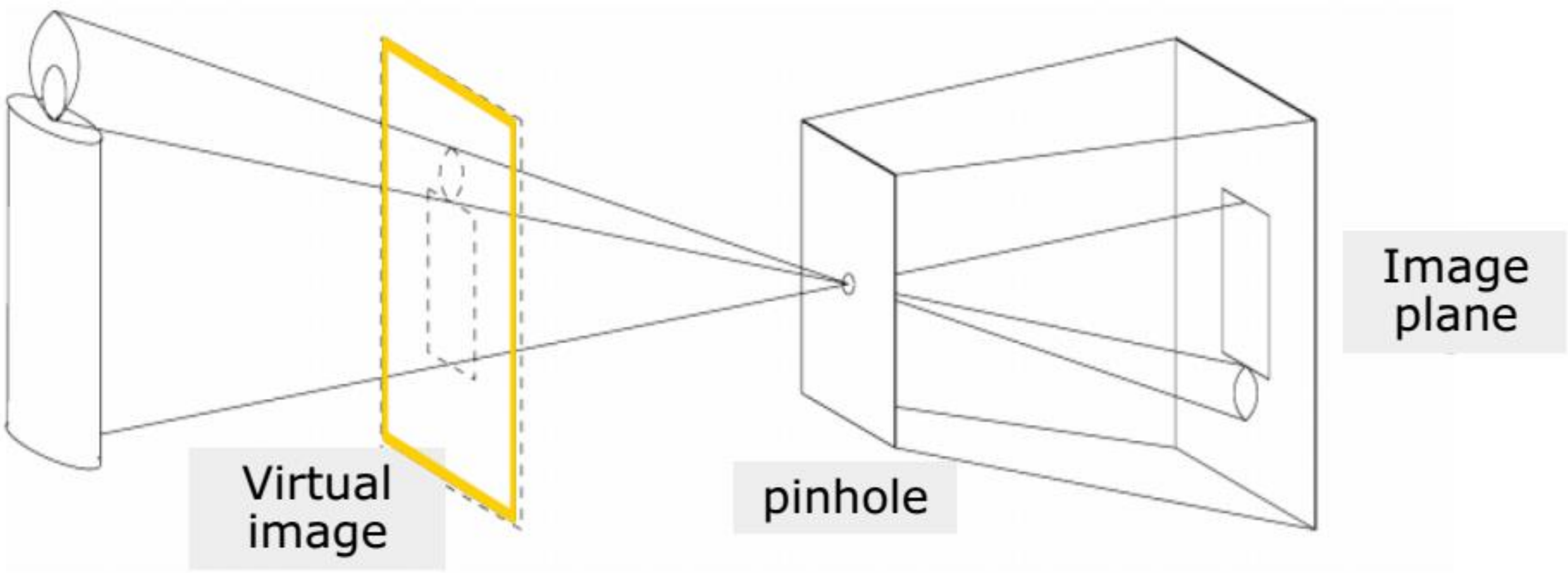
Image Formation

- Add a barrier to block off most of the rays
- This reduces blurring
- The opening is known as the aperture
- How does this transform the image?



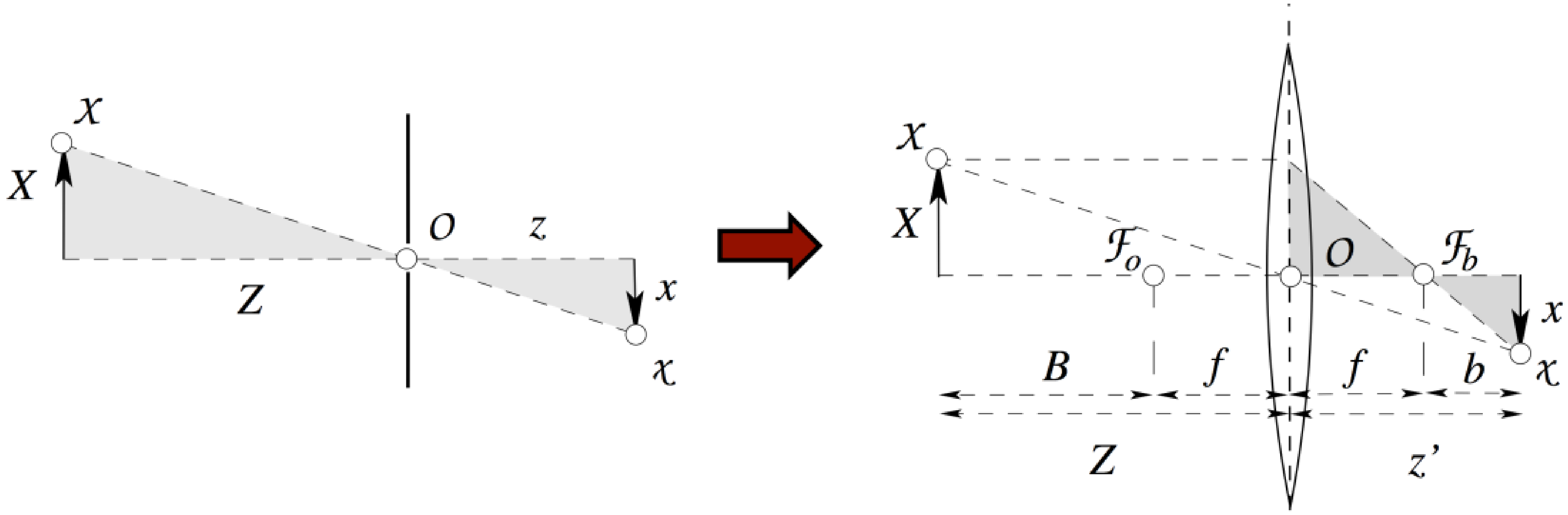
Pinhole Camera

- Pinhole camera is a simple model to approximate the imaging process
- If we treat pinhole as a point, only one ray from any given point can enter the camera



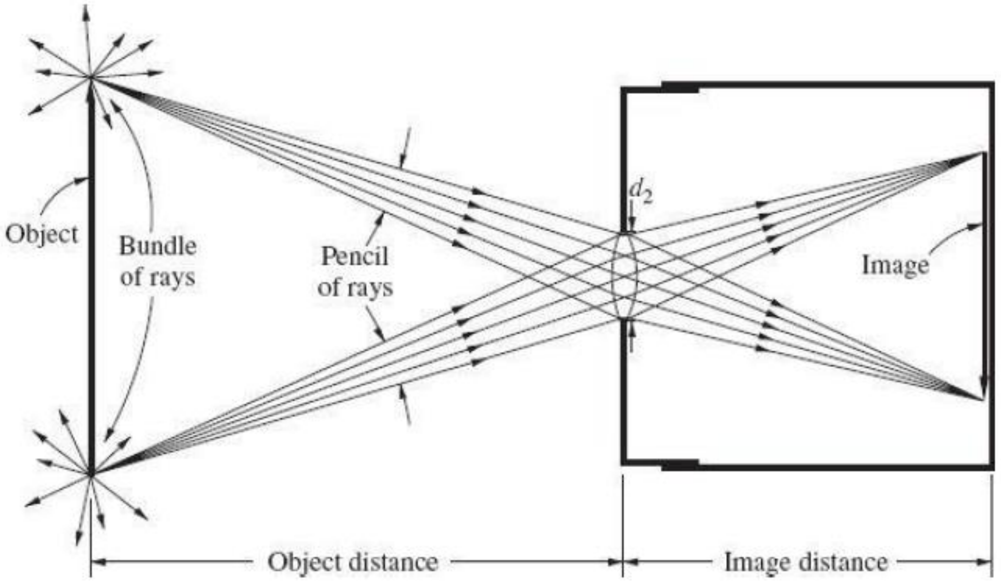
Pinhole Camera Model

- Small hole: sharp image but requires large exposure times
- Large hole: short exposure times but blurry images
- Solution: replace pinhole by lenses



Lens Approximates the Pinhole

- A lens is only an approximation of the pinhole camera model
- The corresponding point on the object and in the image and the center of the lens should lie on one line
- The further away a beam passes the center of the lens, the larger the error
- Use of an aperture to limit the error (trade off between the usable light and price of the lens)



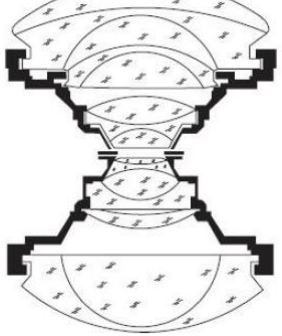
Elements of Camera

lens and camera body

sensor chip

Lenses

- Goal of Lens is to obtain images that are
  - not distorted
  - sharp
  - contrast intensive
- The choice of the lens depends on
  - field of view
  - distance to the object
  - amount of available light
  - price



telephoto normal wide-angle fisheye

Moderate Tele Lens

- Narrow field of view
- Minimal perspective distortions
- Parallel lines remain parallel

Fisheye Lens

- Field of view of 130+ deg
- Straight lines in the world are not straight anymore in the image

Wide Angle Lens

- Useful for application that require a large field of view (70 and 120 deg)
- Straight lines in the world are mapped to roughly straight in the image
- Perspective distortions
- Proportions are not correct anymore

Assumptions Made in the Pinhole Camera/Thin Lens

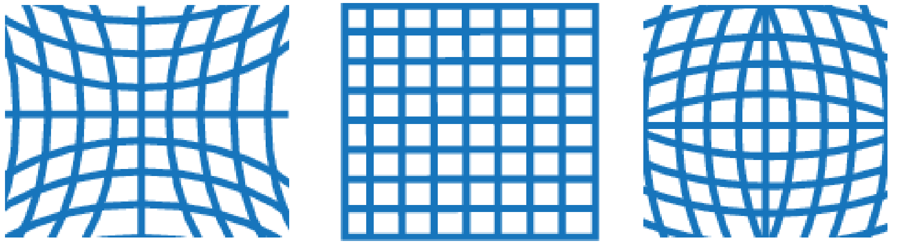
1. All rays from the object point intersect in a single point
2. All image points lie on a plane
3. The ray from the object point to the image point is a straight line

Often these assumption do not hold and leads to imperfect images

Lens Distortions and Aberrations

- It is impossible for a single lens to produce a perfect image;
- blurring, or degrade the sharpness of the image, are termed *aberrations*.
- *Lens distortions*, on the other hand, do not degrade image quality but deteriorate the geometric quality (or positional accuracy)

Lens Distortions - Radial Distortions



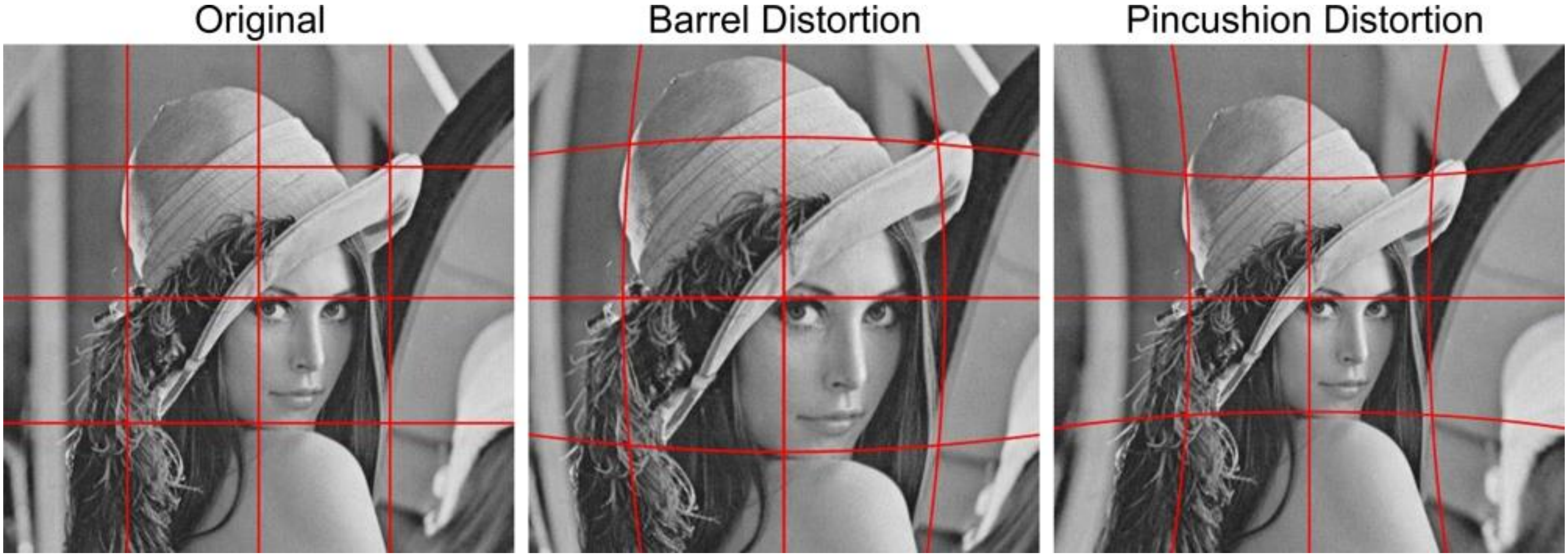
- Radial distortion occurs when light rays bend more near the edges of a lens than they do at its optical center. **The smaller the lens, the greater the distortion**.
- The radial distortion coefficients model this type of distortion. The distorted points are denoted as ($x_{distorted}$, $y_{distorted}$):
- **Typically, two coefficients are sufficient for calibration**. For severe distortion, such as in wide-angle lenses, 3 coefficients are selected including k_3.

$$x_{distorted} = x(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$$

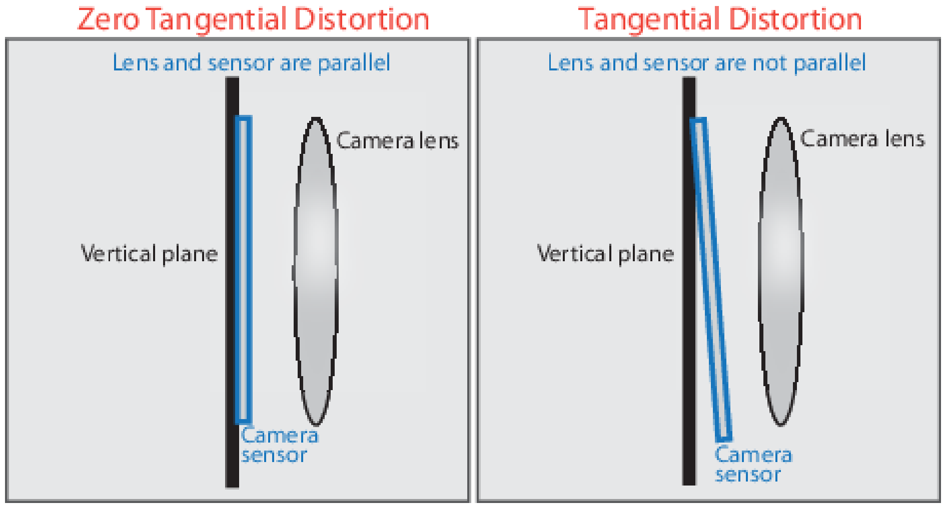
$$y_{distorted} = y(1 + k_1*r^2 + k_2*r^4 + k_3*r^6)$$

- x, y — Undistorted pixel locations. x and y are in normalized image coordinates. Normalized image coordinates are calculated from pixel coordinates by translating to the optical center and dividing by the focal length in pixels. Thus, x and y are dimensionless.
- k_1, k_2, and k_3 — Radial distortion coefficients of the lens.
- r^2: $x^2 + y^2$

Lens Distortions - Radial Distortions



Lens Distortions - Tangential Distortions



- Tangential distortion occurs when the lens and the image plane are not parallel. The tangential distortion coefficients model this type of distortion.

The distorted points are denoted as ($x_{distorted}$, $y_{distorted}$):

$$x_{distorted} = x + [2 * p_1 * x * y + p_2 * (r^2 + 2 * x^2)]$$

$$y_{distorted} = y + [p_1 * (r^2 + 2 * y^2) + 2 * p_2 * x * y]$$

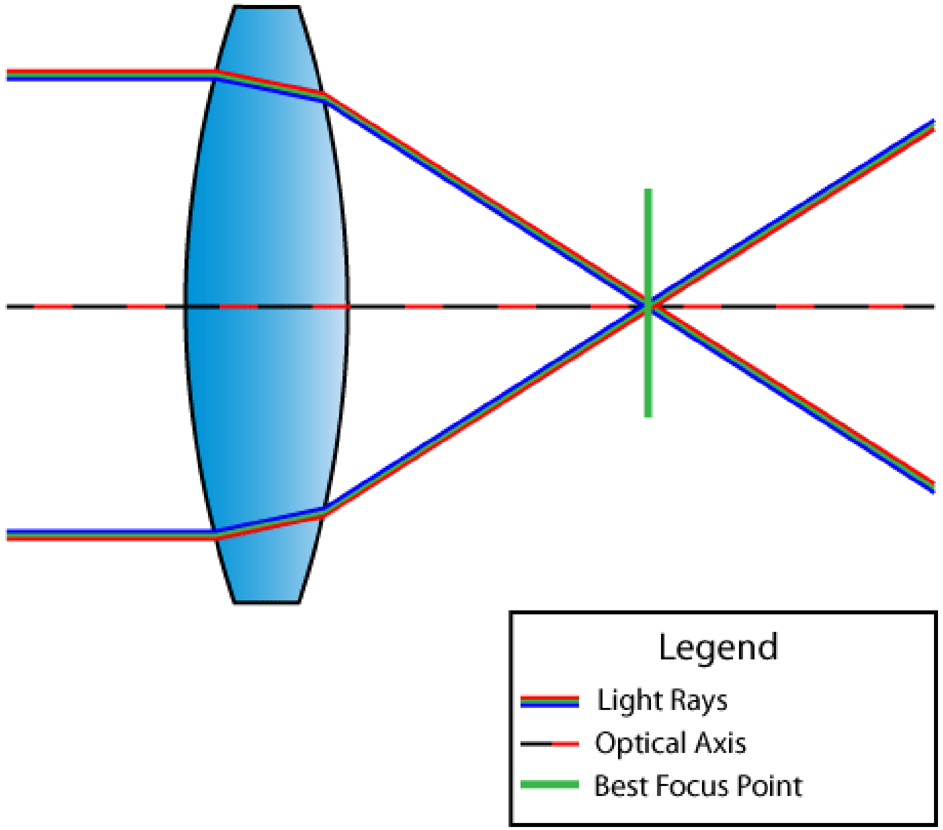
- x, y — Undistorted pixel locations. x and y are in normalized image coordinates. Normalized image coordinates are calculated from pixel coordinates by translating to the optical center and dividing by the focal length in pixels. Thus, x and y are dimensionless.
- p_1 and p_2 — Tangential distortion coefficients of the lens.
- $r^2 = x^2 + y^2$

Camera calibration

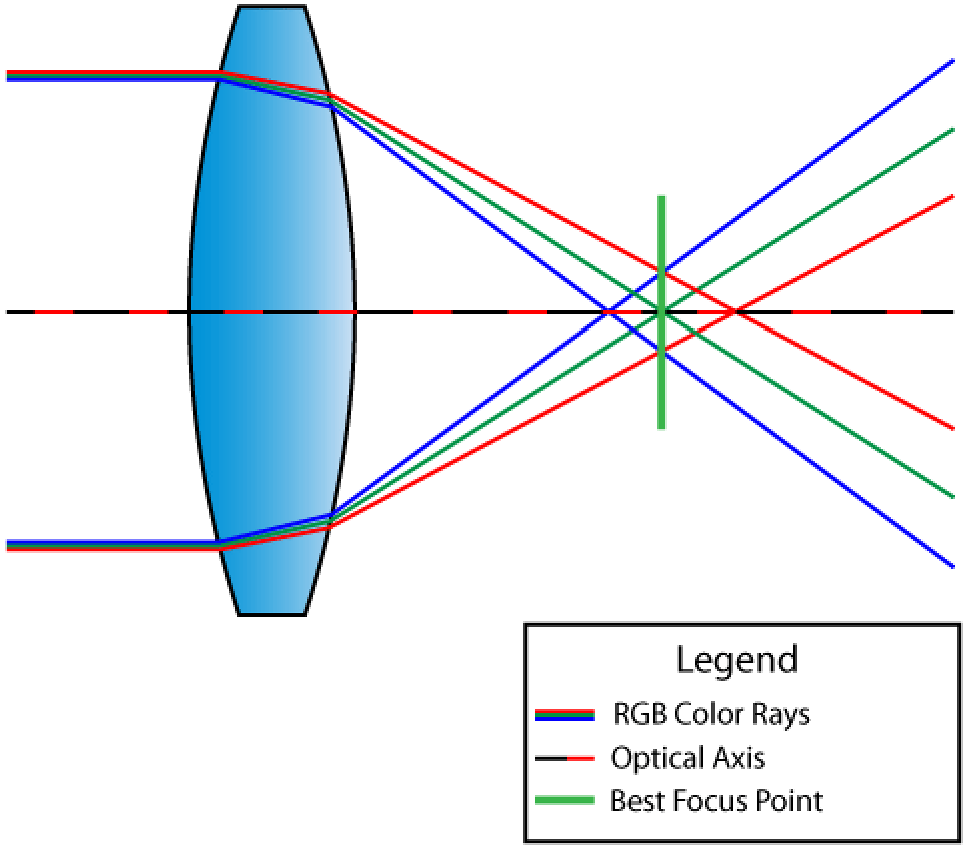
- Required for an exact and precise object reconstruction
- Determination of correct interior orientation parameters
- Compensation of lens distortions and image sensor errors
- Useful also for
  - valuation of the performances of lenses
  - evaluation of the stability of camera
- Parameters involved: -
  - principal point position
  - focal length (camera constant)
  - radial and decentering distortion
  - terms to correct pixel size and shape (scale and shear)

Aberrations

Perfect Lens with no Chromatic Aberration



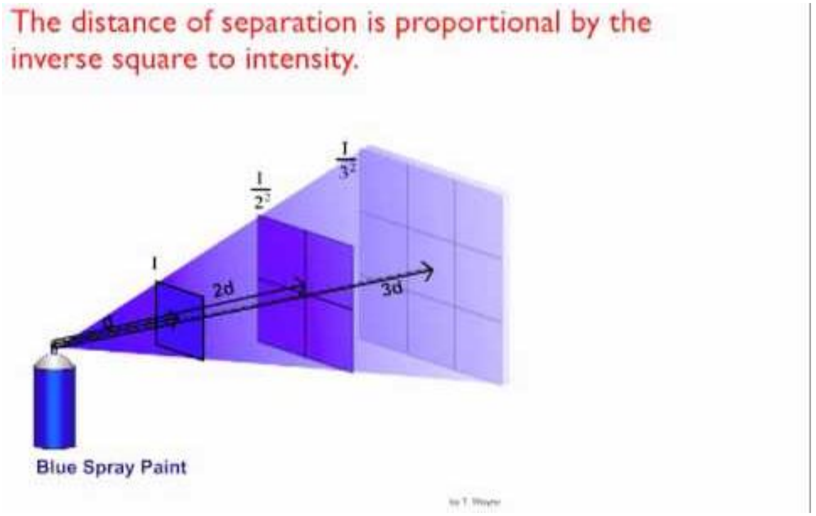
Longitudinal / Axial Chromatic Aberration



Illuminance

Brightness or amount of light received per unit area

- proportional to the amount of light passing through the lens opening during exposure
  - proportional to the d^2
- inversely proportional to the square of distance from the aperture.
  - proportional to $1/i^2$



Illuminance

- illuminance is proportional to d^2/f^2.
- The square root of this term is called the *brightness factor*

$$\sqrt{\frac{d^2}{f^2}} = \frac{d}{f} = \text{brightness factor}$$

- inverse expression of illuminance and is the very common term ***f-stop***, also called *f-number*

$$f\text{-stop} = \frac{f}{d}$$

- ***As the aperture increases, f-stop numbers decrease and illuminance increases, thus requiring less exposure time, i.e., faster shutter speeds.***

Aperture and Depth-of-Field

- The aperture controls the amount of light on the sensor chip and the depth-of-field
- Depth-of-field refers to the range of distance that appears acceptably sharp

Aperture and Depth-of-Field

f/8.0

f/5.6

f/2.8

Aperture and Shutter Speed for Drone Imagery

- Flying Height > focal Length
- High shutter speed – low motion blur (need to have enough light)
- Small aperture (high f number) – High depth of field (need to have adequate light)

Shutter Speed
f number
ISO
} *Let the camera to take care*

Sensor

- The image sensor converts photons to intensity values
- Array of light-sensitive cells

- Two main types of sensors
  - CCD: charge-coupled device (lower noise, more expensive, global shutter)
  - CMOS: complementary metal oxide on silicon (higher noise, cheaper, rolling shutter)

Rolling Shutter Effects

Development of Camera

The remarkable success of photogrammetry in recent years is due in large part to the progress that has been made in developing precision cameras.

- perfection of lenses of extremely high resolving power
- negligible distortion

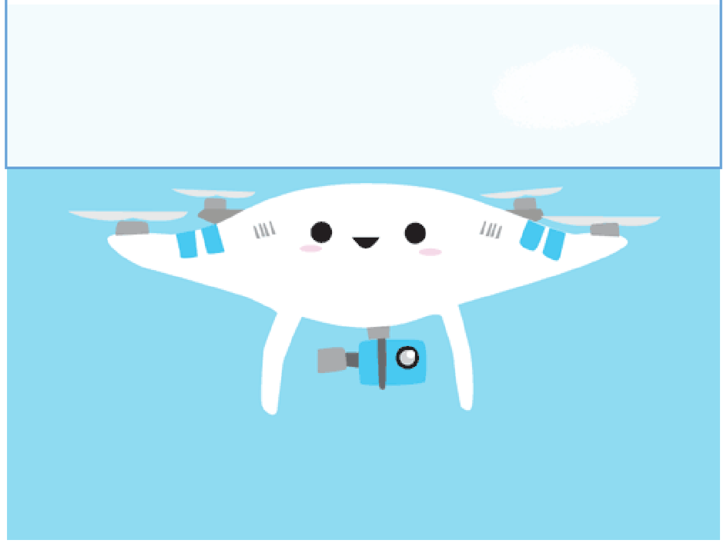
Drones for Mapping – How it Works

Drone

- Platform to carry imaging sensor through accurate flight path.

Camera

- Captures overlapping images while in motion

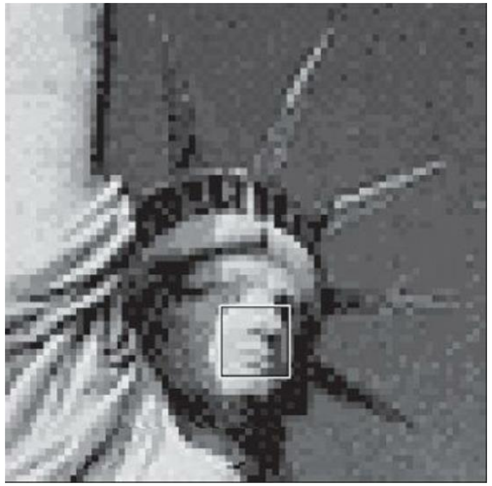


Algorithm

- Computer Vision + Photogrammetry
- Extracts geometry through matches of thousands of key-points for generating accurate maps and 3D models.

Images

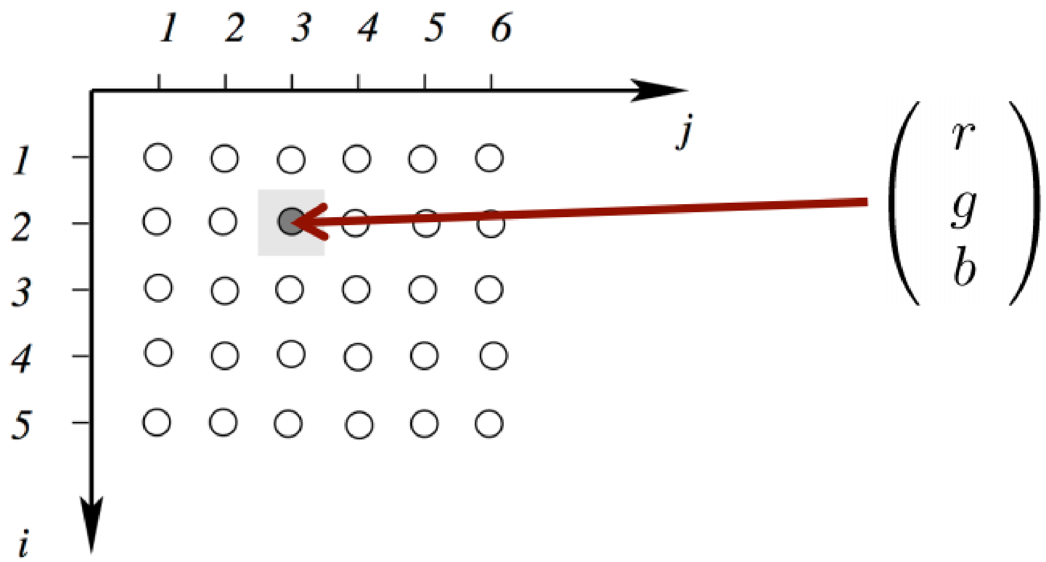
- A digital image is a computer-compatible pictorial rendition in which the image is divided into a fine grid of “picture elements,” or *pixels*.
- In fact consists of an array of integers, often referred to as *digital numbers*, each quantifying the *gray level*, or degree of darkness, at a particular element.



190	237	234	223	227	220	219	231	115	2
237	227	223	228	229	237	229	219	190	1
231	227	223	227	229	219	196	216	217	96
229	218	220	219	160	120	164	183	127	136
219	218	219	213	214	210	113	2	54	127
217	213	223	227	223	222	199	54	70	128
219	217	207	196	183	187	207	149	74	126
217	216	210	218	217	203	145	70	73	127
207	223	227	203	145	127	200	136	75	80
227	219	218	223	219	190	115	70	71	74

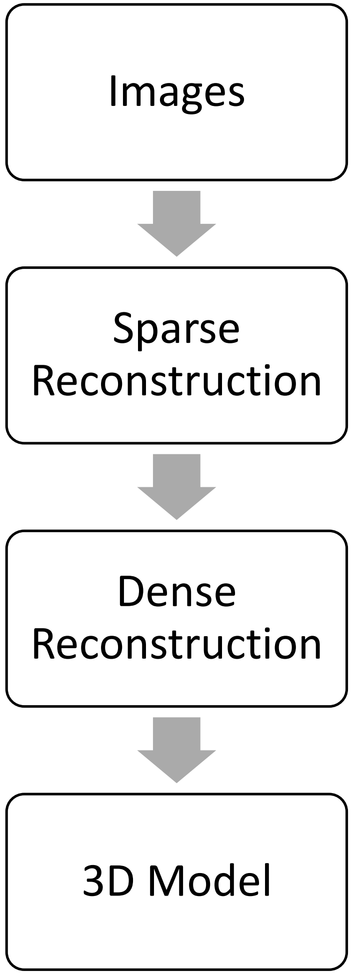
Images

Each Pixel Can be a Vector



- 3D vector for storing color information

General Workflow of Modern Sfm



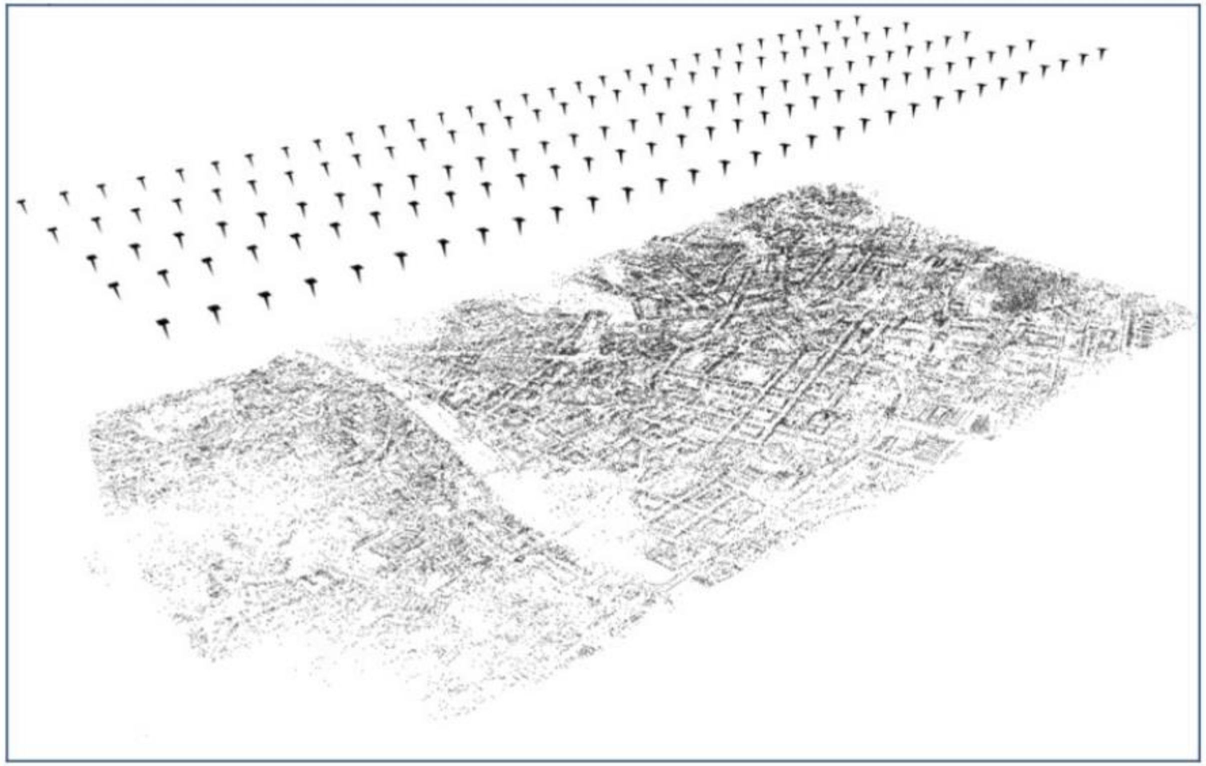
Determine the Projection Matrix which is combination of→
Camera Matrix (by Camera calibration or Auto Calibration) &
Exterior Orientation Matrix (by Feature Matching)

Using determined projection matrix for every selected image build dense point cloud

Build the Surface

All are "Black Box" Processes
But make our life easy….

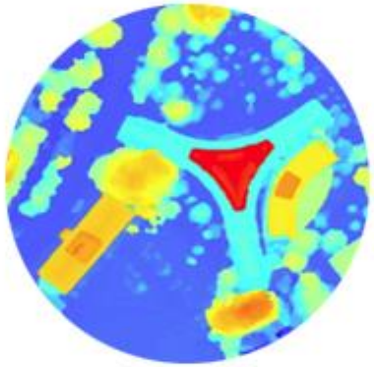
Flight Planning



Why flight planning is important in the overall photogrammetric project?

- How the flight should be carried out to obtain the products in required accuracy
- Gives optimum specifications for a project, can be prepared only after careful consideration of all the many variables which influence aerial photography.
- In many areas, period of time that are acceptable for aerial photography are limited by weather & ground cover conditions which are related to seasons of the year.
- Proper Planning = No waste of money and time

Orthoimages



Digital Surface Models

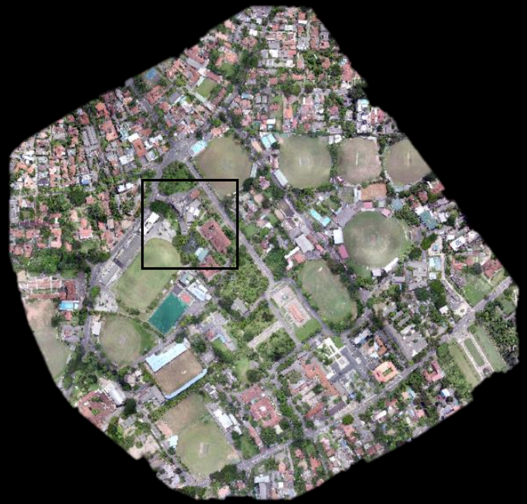
3D Models

- Clear understanding about what exactly needed to be produced
    - How the resulting data is going to be used: ex. Planning, Monitoring, Validating, supporting other data, etc.

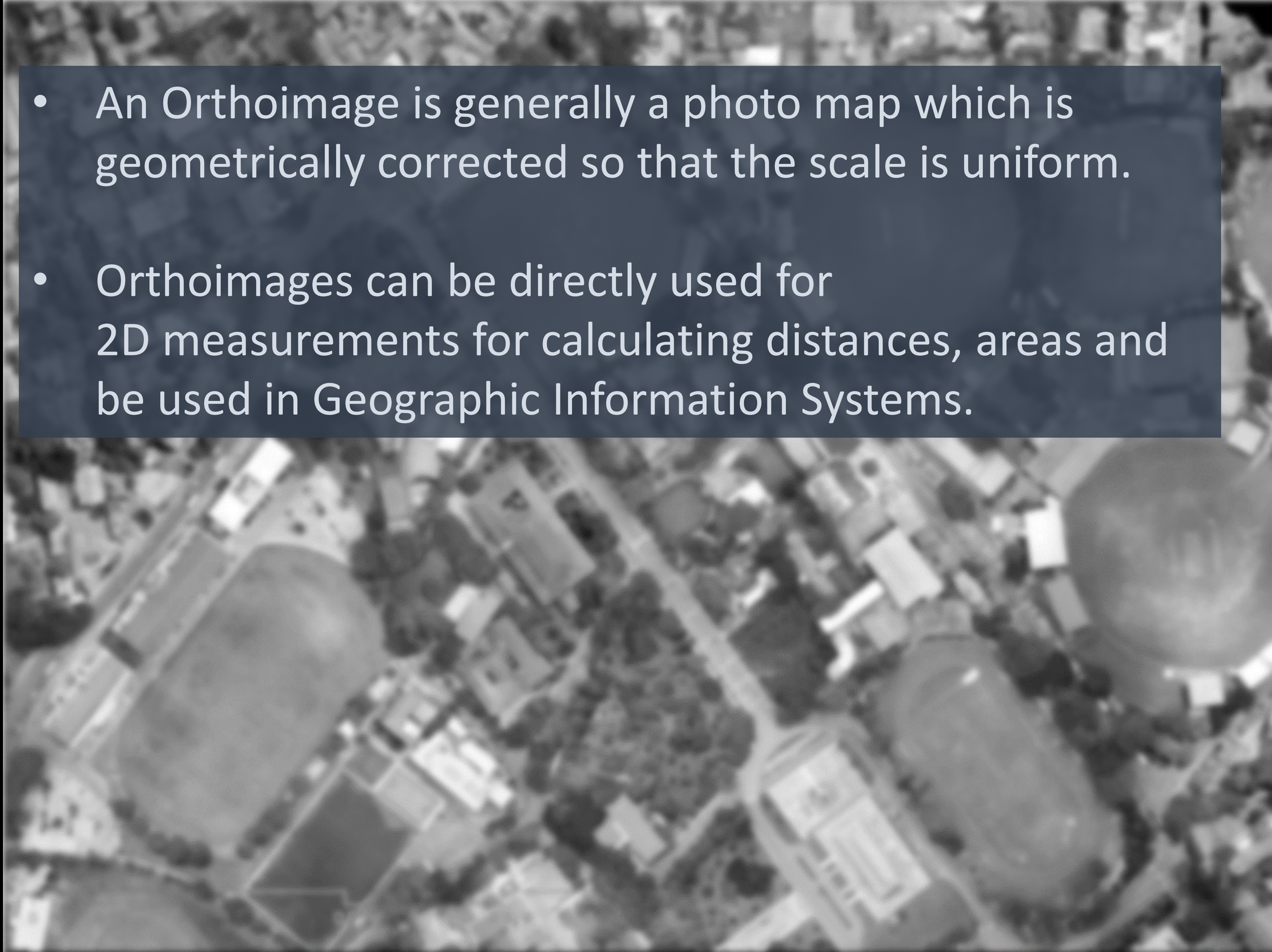
Start with the **END** in mind

Orthoimage

Resolution: 5 cm

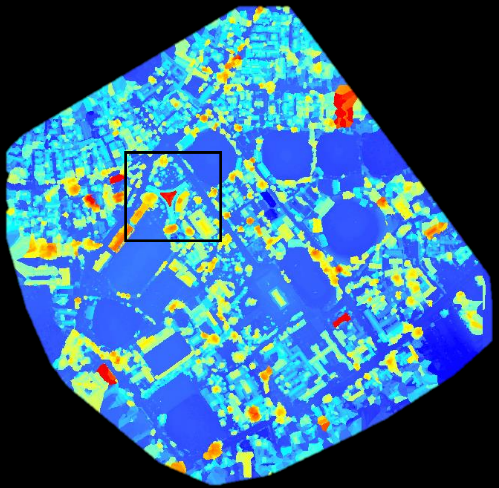


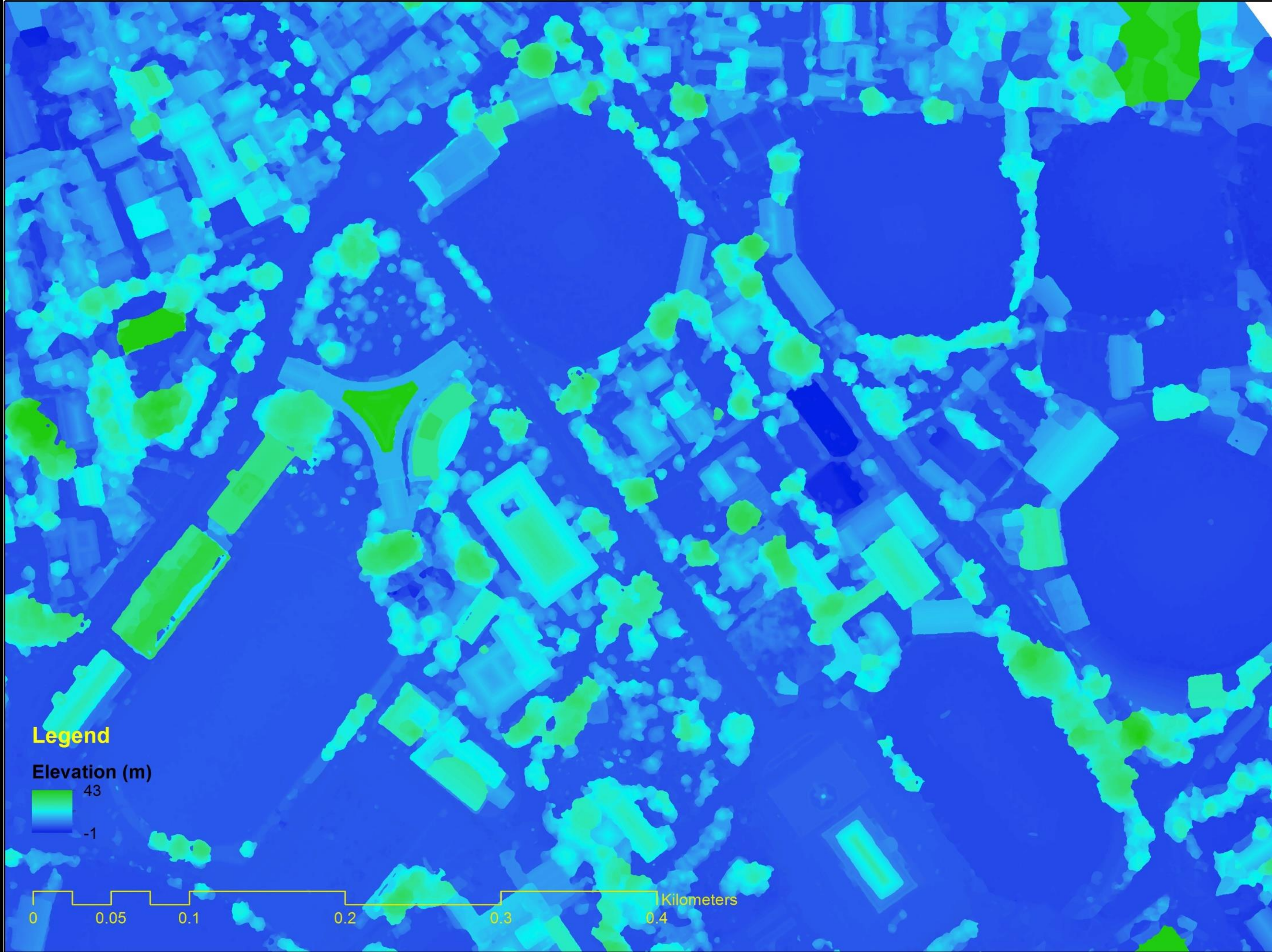
Orthoimage



- An Orthoimage is generally a photo map which is geometrically corrected so that the scale is uniform.
- Orthoimages can be directly used for 2D measurements for calculating distances, areas and be used in Geographic Information Systems.

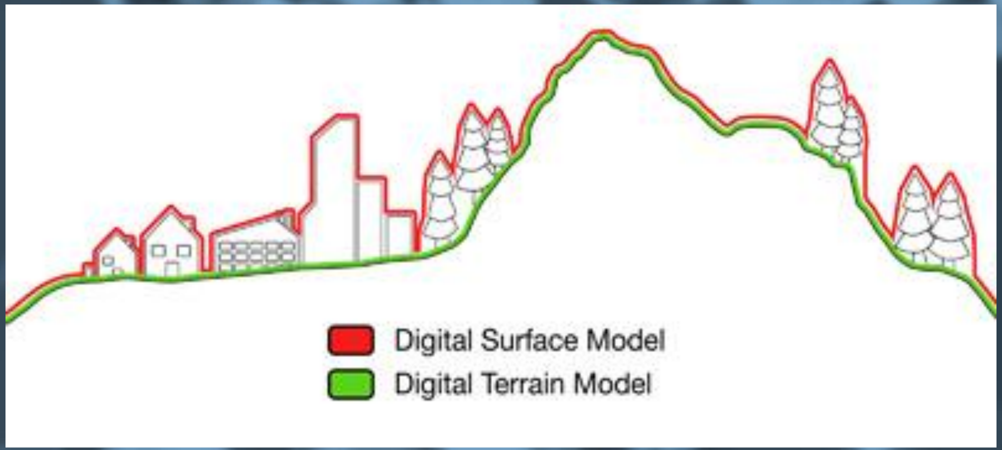
DSM





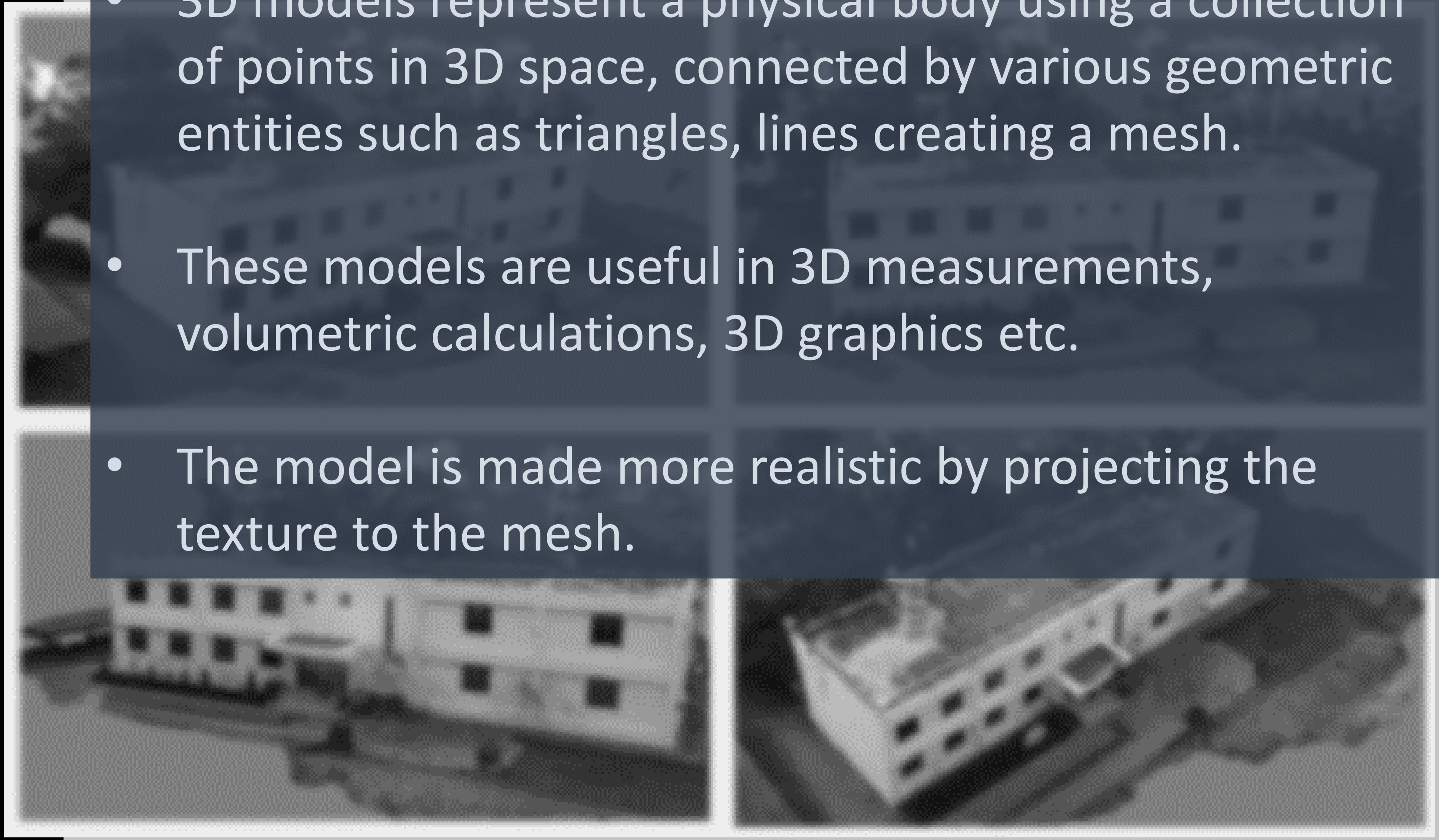
DSM

- A Digital Surface Model or DSM is digital 3D representation of an area by elevation.
- Each pixel of the raster image is assigned to represent the elevation of the location at the relevant pixel.



3D Model

3D Model



- 3D models represent a physical body using a collection of points in 3D space, connected by various geometric entities such as triangles, lines creating a mesh.
- These models are useful in 3D measurements, volumetric calculations, 3D graphics etc.
- The model is made more realistic by projecting the texture to the mesh.

Factors to be considered when planning a flight mission:

- Purpose of the project
- Layout of the area (a flight map)
- Direction of fight lines
- The type of the camera to be used
- Time of year/day
- Weather condition
- Time schedule
- External condition (cost, etc)
- A scale of the photography
- Forward & side overlaps
- Flying height
- Tilt & drift tolerance etc.

Weather & Seasonal considerations

- Cloud conditions,
  - **For drones; Good cloud cover with adequate lighting is preferred** as clouds provide even distribution of sun light
  - ideally < 10% for traditional aerial mapping
- Minimize Shadows
  - 11 AM to 1PM is the ideal time
- Seasonal Effects ex:
  - Leaf-off: spring/fall when deciduous tree leaves are off and ground free of snow used for topographic/soils mapping, terrain/landform interpretation
  - Leaf-on: summer when deciduous trees are leafed out or late fall when various tree species may be identified by foliage colour used for vegetation analyses

Scale considerations

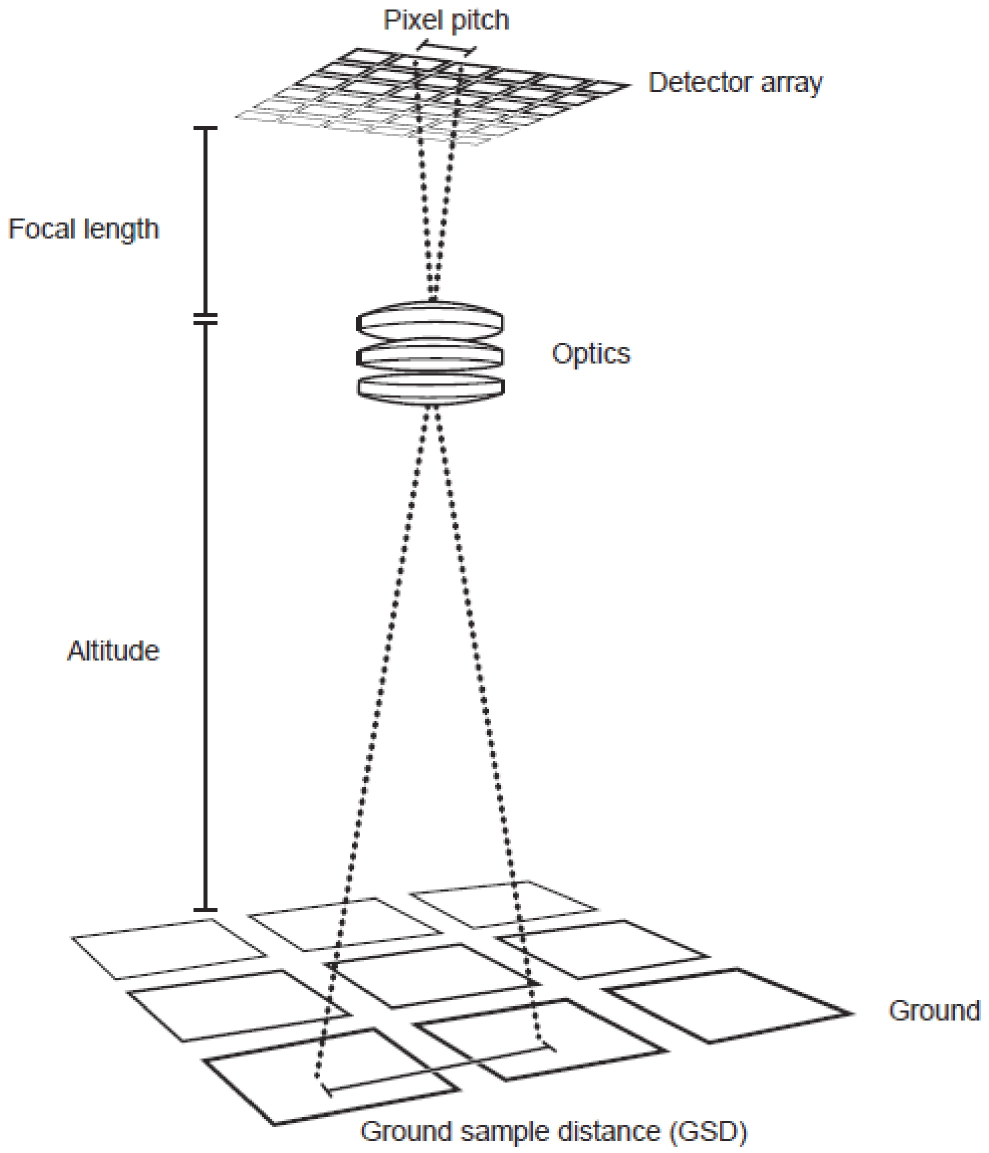
- What is the minimum mapping unit/ **Resolution** or size of smallest object that you want resolved and mapped?
- What is the ground coverage desired for an individual photo?
- How large of a study area to be covered?

Resolution is function of flying height and camera focal length

Exercise

Calculate the appropriate flying height for phantom 3 professional drone to obtain 5 cm/px ground sampling distance

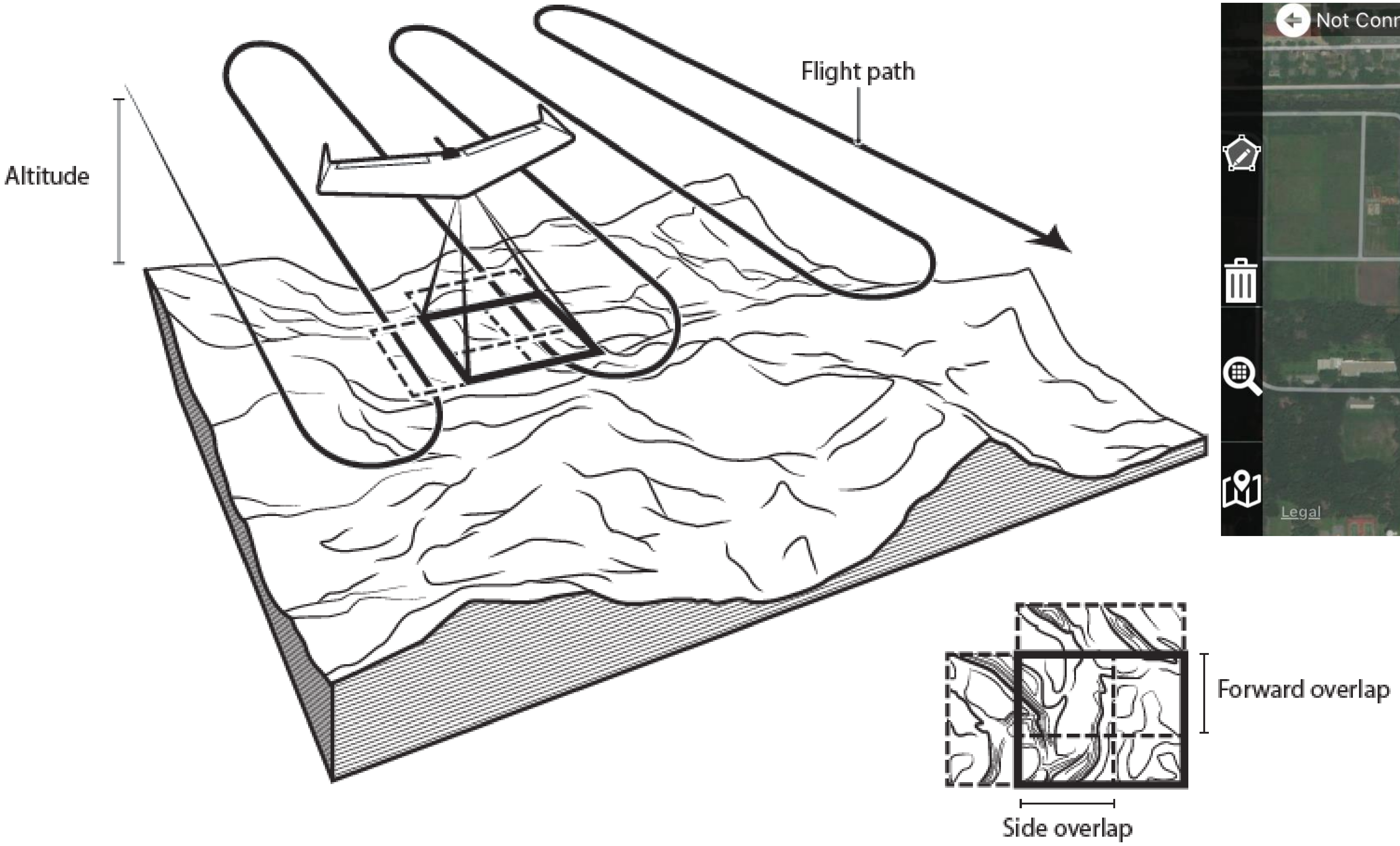
- Guide
  - Its simple projective geometry - very easy ;)
  - All required parameters of the drone: http://www.dji.com/phantom-3-pro/info#specs

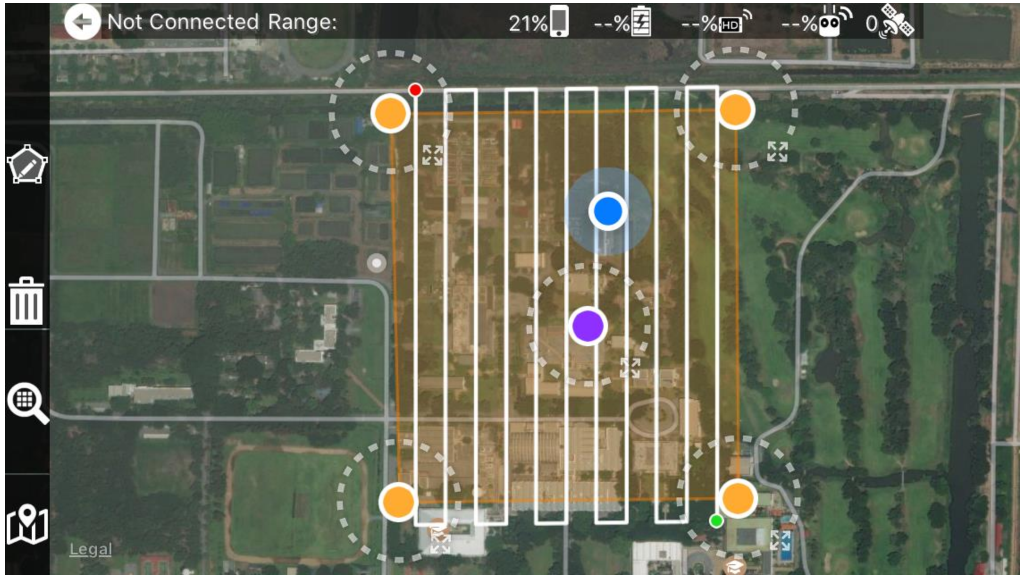


Flight Alignment

- When an area is covered by vertical aerial photography, the photographs are usually taken along a series of parallel passes, called flight strips.
- Flight lines are planned to be parallel
- For maximum aircraft efficiency, they should be parallel to the long axis of the study area (minimize aircraft turns).
- Crab or drift should be minimized
- Tilt , 2-3^{o} for any single photo, average < 1^{o} for entire project for general mapping

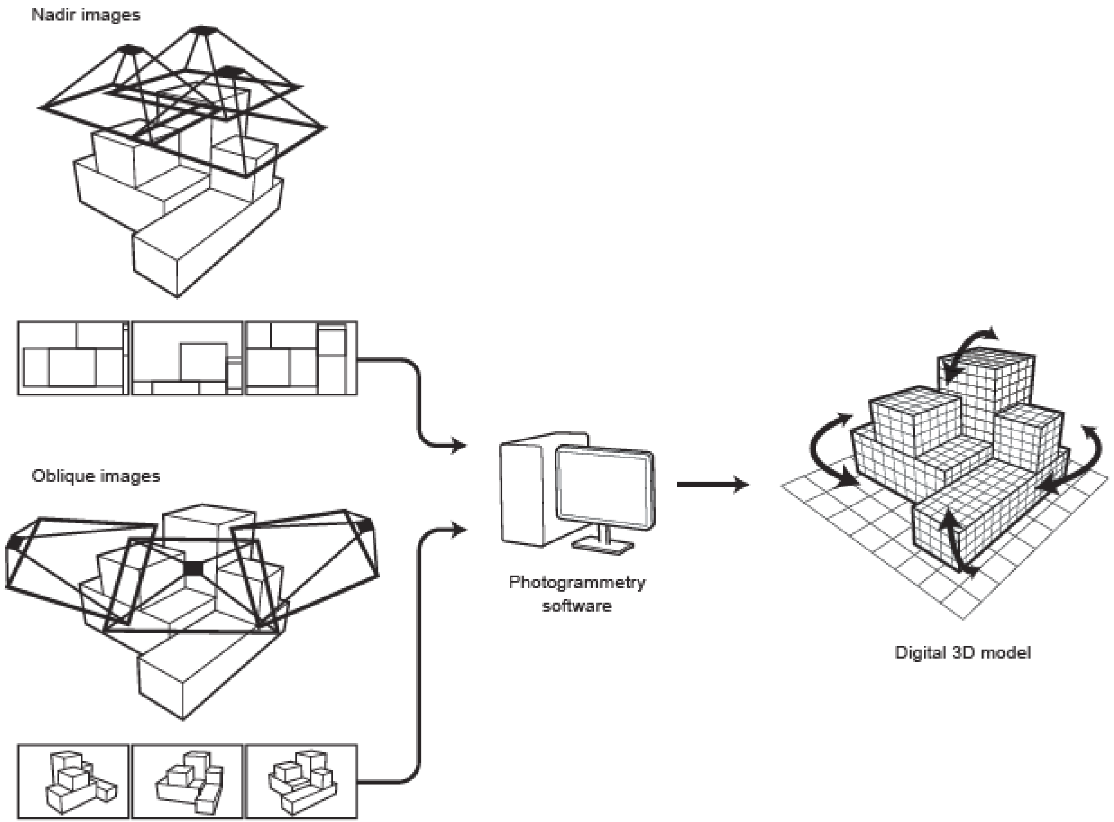
Flight Alignment





Flight Alignment

- Highly dependent on your application
- Ex: 3D modelling



Photogrammetry software combines information from multiple images taken from both overhead and to the side to create 3D models.

Flight Alignment

3D Mapping

- In general, ortho-photo and DSM made by UAV imagery are made to represents the top most surface. UAV flight plan is designed accordingly to represent the top most surface with high geometric accuracy.
- But in some urban/semi urban areas important features (roads, foot paths, buildings) are hidden by tree canopy or some other features.
- study is carried out to **find out a methodology to extract such hidden features up to acceptable extent by 3D model obtained from UAV imagery** using photogrammetric techniques.

Case study in AIT

Coverage area	: 0.141 km^2
Flight Parameters	
Flying height	: 100m AGL
GSD	: 4.9 cm/pix
Overlap (Side & Forward)	: 80%
No of control points	: 5
No of check points	: 3

Case 1 : General Case
near vertical photos; 1 regular grid

In general case, near vertical photographs (tilt angle < 3deg) is used to generate orthoimage and DSM because of high geometric quality of such images. Near vertical images only represent accurate 2.5D model of the scene as it lacks details to representation of full 3D model.

Covered features are hard to be identified.

Case 1 : General Case
near vertical photos; 1 regular grid

Geo-location Accuracy

Label	XY error (m)	Z error (m)	Error (m)	Projections	Error (pix)
pgcp5	0.0268398	-0.0801485	0.0845231	9	0.204
pgcp9	0.0261135	-0.0761792	0.0805306	20	0.448
pgcp10	0.0214069	-0.147265	0.148813	19	0.410
Total	**0.0249035**	**0.106323**	**0.109201**		**0.397**

Table 4. Check points.

No of images: 219
Processing Time: ~4.5h (upto dense cloud)

Case 1 : General Case
near vertical photos; 1 regular grid

Overview of Result

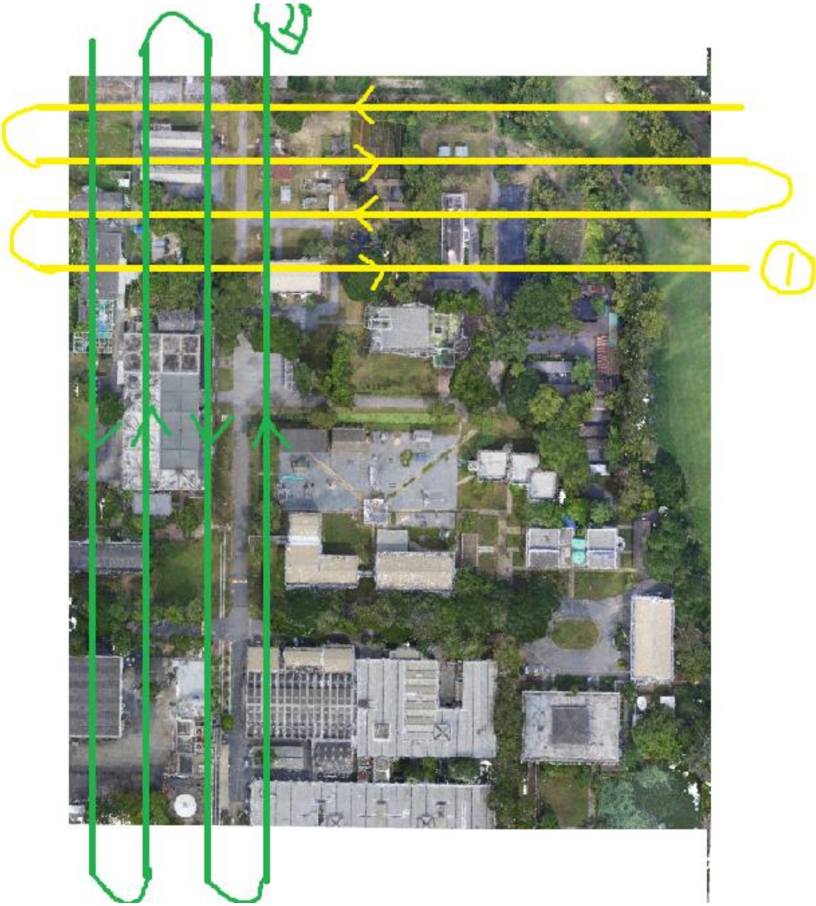
- High geolocation accuracy: 2.4cm horizontal 11cm vertical
- Geometrical errors in sides of features (eg: building facades)
- 3D model (point cloud) accurately represents features which are represented in orthoimage. Some important points underneath, are not being reconstructed.
- Textured 3D model: https://skfb.ly/XP9R

Case 1 : General Case
near vertical photos; 1 regular grid

Buildings covered by tree canopy (which are not visible in Orthoimage) are deformed in the 3D model.
Geometry can not be extracted accurately

Case 2: Double Grid

near vertical photos 1 regular grid + ~45 deg oblique perpendicular grid



1 – near vertical images
2 – ~45 deg oblique images

For detailed 3D reconstruction of an urban or semi urban area; flight plan should be designed to acquire most of details such as building facades in every direction (north, east, south, west)

A double grid is used with high overlap (80%) as 1st grid covering the area by near vertical photos and 2nd grid by oblique images perpendicular to the first grid

Vertical photos: High geometric accuracy; low details
Slant images: low geometric accuracy; high details

Case 2: Double Grid
near vertical photos 1 regular grid + ~45 deg oblique perpendicular grid

Geo-location Accuracy

Label	XY error (m)	Z error (m)	Error (m)	Projections	Error (pix)
pgcp5	0.0508449	-0.00789048	0.0514535	27	0.439
pgcp9	0.01116	-0.0076085	0.0135068	55	0.420
pgcp10	0.032278	-0.0478186	0.0576931	52	0.433
Total	**0.035363**	**0.0283241**	**0.0453078**		**0.429**

Table 4. Check points.

No of Images : 341
Near Vertical : 129
Oblique : 212
Processing time : ~ 12h

Case 2: Double Grid near vertical photos 1 regular grid + ~45 deg oblique perpendicular grid

Overview of Result

- High location accuracy: 3.5 cm horizontal 3 cm vertical
- 3D point cloud represents the features (building / trees) with less distortions and greater amount of details
- 3D model can be used to identify important feature which are not visible in the orthoimage or general 3D model
- Increased computational complexity and increased time for processing.
- Textured 3D model: https://skfb.ly/XPsG

Case 2: Double Grid

This building is almost fully covered by tree canopy which makes unable to accurately detect its size and shape by top view ortho images. But in the textured 3d model the building is easily visible.

Orthoimage

Textured 3D model

Comparision case 1 vs case 2

Case 1

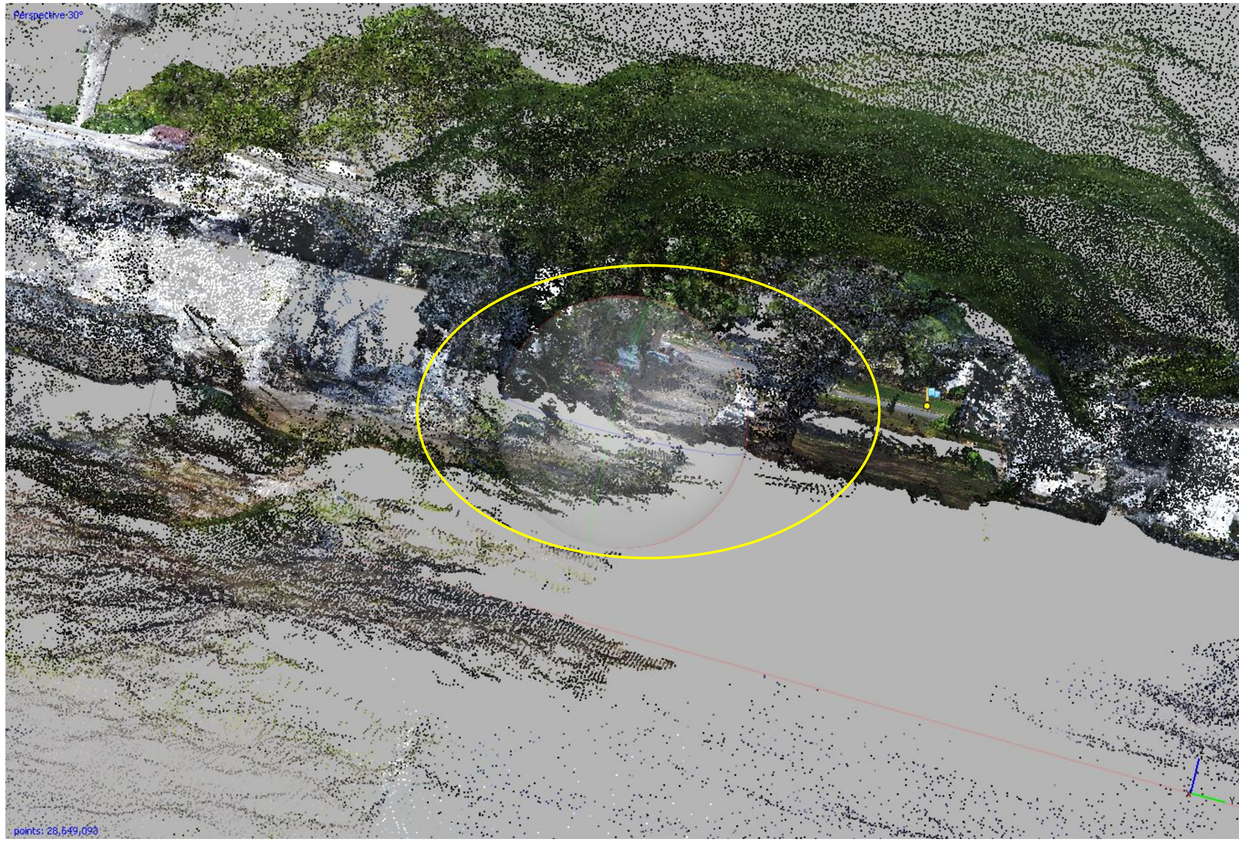
Case 2

Comparison case 1 vs case 2

Eg: The road in front of the energy building is highly covered by tree canopy. It is not possible to mark any point underneath just by orthoimage.

Comparison case 1 vs case 2

Case 1



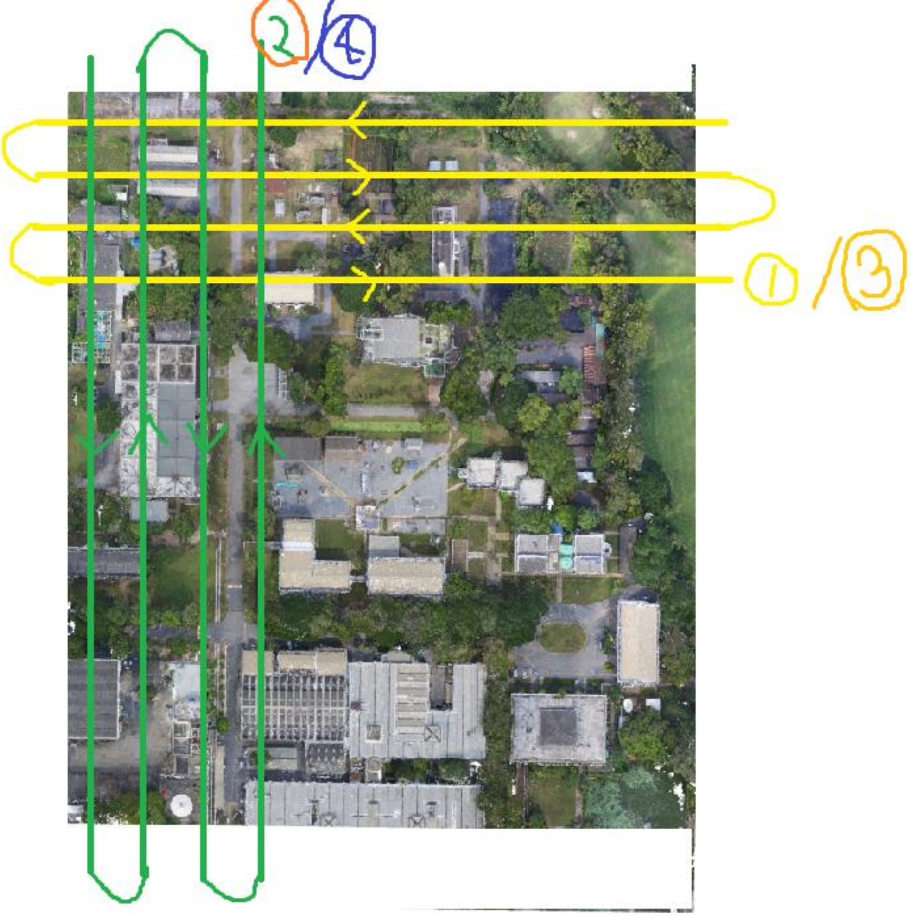
Case 2

Case 3: Quad Grid

near vertical photos – 2 perpendicular grids

+

~45deg oblique photos – 2 perpendicular grid



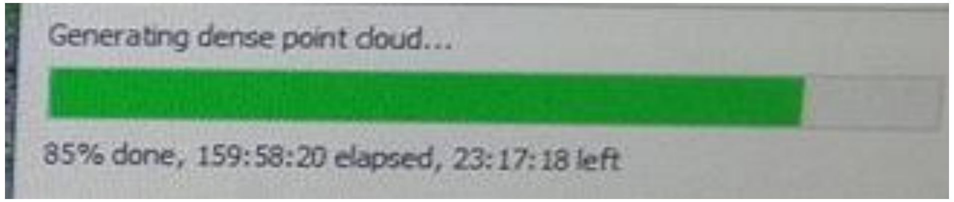
1,2 – near vertical photos
3,4 - ~45deg oblique images

Maximum amount of details and accuracy for given flying height can be obtained using this configuration

Trade off between details/accuracy vs processing time

Very intensive processing; require more time and higher processing power

Processing Time : 150++ h



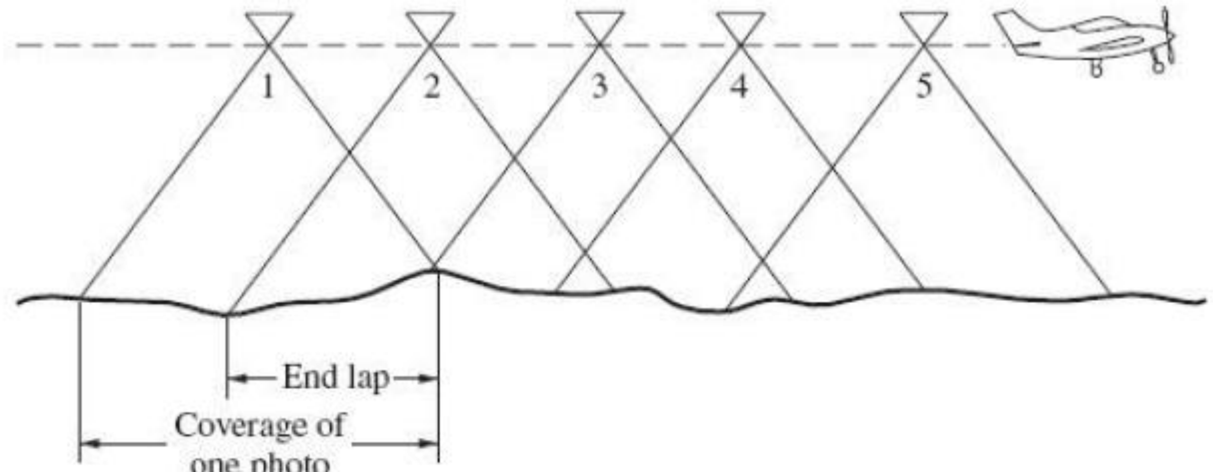
Case 3: Quad Grid near vertical photos 2 perpendicular grids + ~45 deg oblique 2 perpendicular grids

Geo-location Accuracy

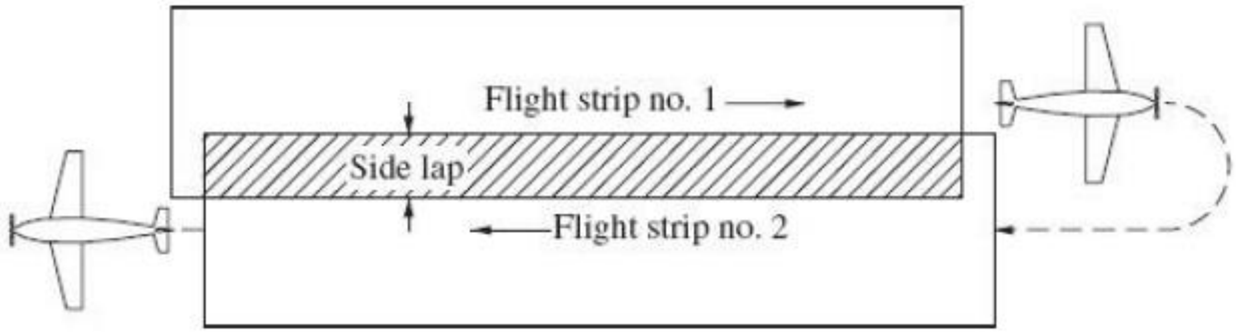
Label	XY error (m)	Z error (m)	Error (m)	Projections	Error (pix)
pgcp9	0.0245659	0.0438271	0.0502424	102	0.642
pgcp5	0.0392221	0.0085397	0.0401409	41	0.414
pgcp10	0.004618	-0.0285416	0.0289128	87	0.377
Total	**0.0268525**	**0.0305961**	**0.0407085**		**0.517**

No of Images : 649
Near Vertical : 271
Oblique : 378
Processing time : ~ 170h

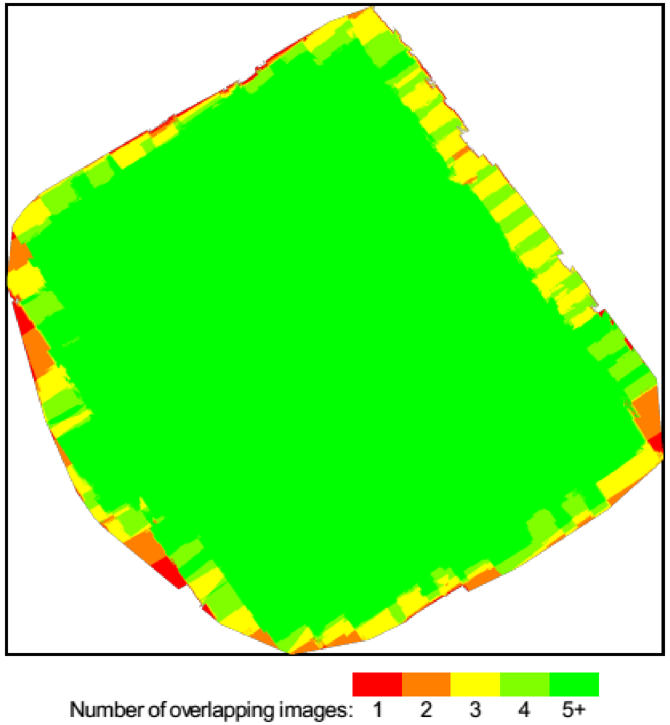
Photographic End & Side lap



End lap of photographs in a flight strip.



Side lap of adjacent flight strips.



80% Fw Overlap and 70% Side Overlap of Phantom 3 images @100m AGL

Remark

Flat terrain with agricultural fields:

In cases where the terrain is flat with homogeneous content, such as agriculture fields, it is difficult to extract common characteristic points (key-points) between the images. In order to achieve good results, it is recommended to use a **Single or Double grid** applying the following settings:

- At least 85% frontal overlap and at least 70% side overlap.
- Increase the flight height. In most cases, flying higher improves the results.

Remark

Forest and dense vegetation:

Trees and dense vegetation often have a different appearance between overlapping images due thousands of branches and leaves. Therefore, it is difficult to extract common characteristic points (**key points**) between the images. In order to achieve good results, it is recommended to use a **Single or Double grid mission** applying the following settings:

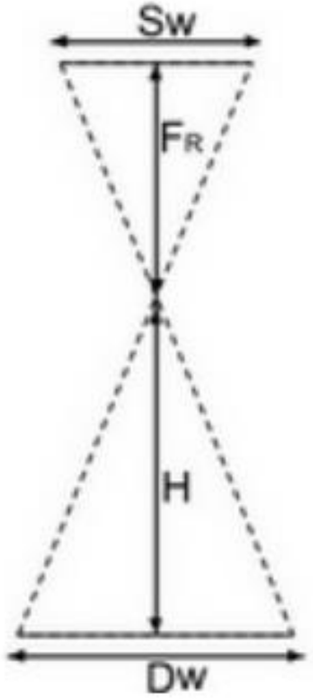
- At least 85% frontal overlap and at least 70% side overlap.
- Increase the flight height. At higher altitude, there is less perspective distortion, therefore causing less appearance problems.) In other words, it is easier to detect visual similarities between overlapping images.
- The flight height in combination with the image pixel resolution and the focal length determine the Ground Sampling Distance (spatial resolution) of the images.
- Best results are obtained with a **GSD higher than 10cm/pixel**.

How flight plan is calculated

Ground Sampling Distance (GSD):

The Ground Sampling Distance (GSD) is the distance between the center of two consecutive pixels on the ground.

- It influences the accuracy and the quality of the final results as well as the details that are visible in the final Orthomosaic.
- The flight height [**H**] that is needed to obtain a given GSD can be computed and depends on the camera focal length [**Fr]**, the camera sensor width [**Sw**], and the image width [**Dw**].



$H / F_R = D_W / S_W$ ➔ ***H*** *= (DW * FR) / SW (1)*

Sw = real sensor width [mm]
FR = real focal length [mm]
H = flight height [m]
Dw = distance covered on the ground by one image in the width direction (footprint width) [m]

How flight plan is calculated

<u>**Ground Sampling Distance (GSD):**</u>

Flying height (**H**):

$H / F_R = D_W / S_W$ ➔ ***H** = (DW * FR) / SW* *(1)*

Distance covered on the ground (**Dw**):

$D_W = (imW * GSD) / 100$ *(2)*

Combining (1) and (2)

*H [m] = (imW * GSD * FR) / (SW * 100)* *(3)*

Note: The result is given in [m], considering that the GSD is in [cm/pixel].

Sw = real sensor width [mm]
FR = real focal length [mm]
H = flight height [m]
Dw = distance covered on the ground by an image in width direction (footprint width) [m]
imW = image width [pixel]
GSD = desired GSD [cm/pixel]

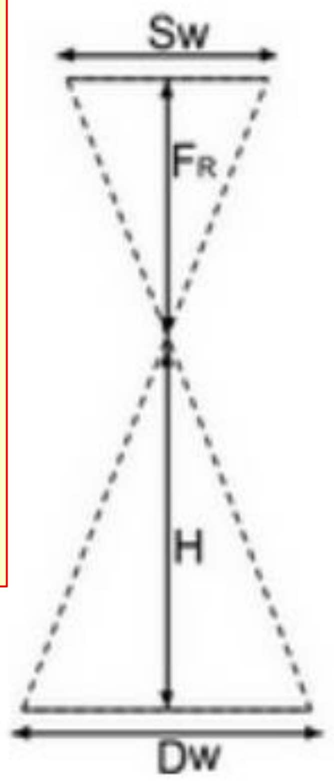
How flight plan is calculated

Ground Sampling Distance (GSD):

Computation of the flight height to get a GSD of 5 [cm/pixel]:

- using a camera with a real focal length of 5 [mm] and a real sensor width of 6.17 [mm].
- Assuming that the image width is 4000 [pixels] and using the equation (4), the **flight height should be 162 [m]**.

*H = (imW * GSD* FR) / (Sw * 100) = (4000 * 5 * 5) / (6.17 * 100)*
*= **162.07 [m]***

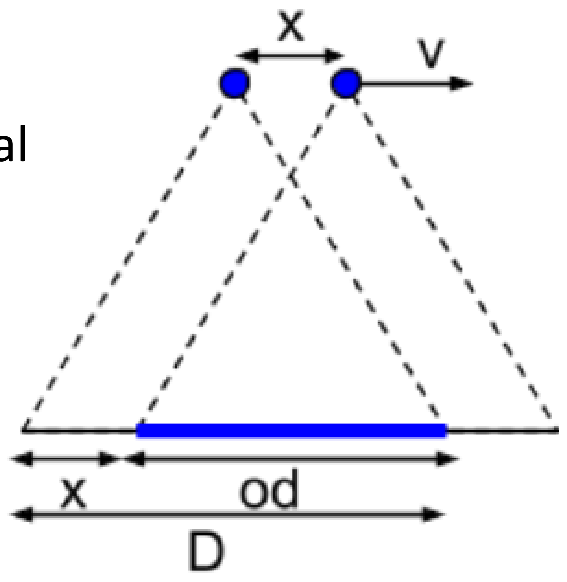


Sw = real sensor width [mm]
FR = real focal length [mm]
H = flight height [m]
Dw = distance covered on the ground by an image in width direction (footprint width) [m]
imW = image width [pixel]
GSD = desired GSD [cm/pixel]

How flight plan is calculated

Image Rate for a given Frontal Overlap:

The image shooting rate to achieve a given frontal overlap depends on the speed of the UAV/plane, the GSD and the pixel resolution of the camera. The higher the overlap, the easier it is for the software to find common points.



$$Od = overlap * D \quad (1)$$
$$X = D - od \quad (2)$$
$$t = x / v \quad (3)$$
$$D = Dh = (imH * GSD) / 100 \quad (4)$$

od = *overlap between two images in the flight direction [m]*
overlap = *desired frontal overlap between two images [%]*
D = *ground distance covered by one image in the flight direction [m]*
X = *distance between two camera positions in the flight direction [m]*
v = *flight speed [m/s]*
t = *elapsed time between two images (image rate) [s]*
Dh = *ground distance covered by one image in the height direction (footprint height) [m]*
imH = *image height (in the flight direction) [pixel]*
GSD = *desired GSD [cm/pixel]*

How flight plan is calculated

<u>**Image Rate for a given Frontal Overlap:**</u>

*Od = overlap * D* (1)

x = D - od (2)

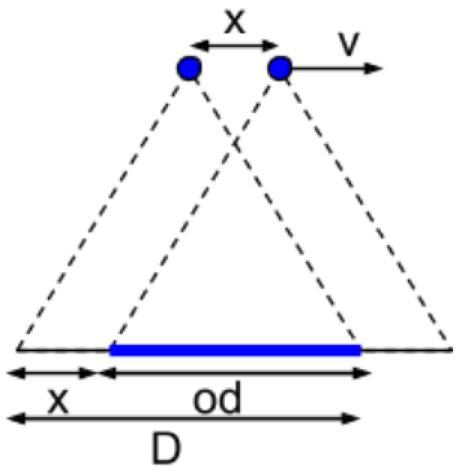
*D = Dh = (imH * GSD) / 100* (4)

Substituting (1) and (4) into Equation (2):

*x = Dh - overlap * Dh*

*x = Dh * (1 - overlap)*

x = ((imH GSD) / 100) * (1 - overlap)* (5)



Note: x is given in [m], considering that the GSD is in [cm/pixel].

od = *overlap between two images in the flight direction [m]*
overlap = *desired frontal overlap between two images [%]*
D = *ground distance covered by one image in the flight direction [m]*
x = *distance between two camera positions in the flight direction [m]*
v = *flight speed [m/s]*
t = *elapsed time between two images (image rate) [s]*
Dh = *ground distance covered by one image in the height direction (footprint height) [m]*
imH = *image height (in the flight direction) [pixel]*
GSD = *desired GSD [cm/pixel]*

How flight plan is calculated

Image Rate for a given Frontal Overlap:

In order to achieve an overlap of 75% (overlap = 0.75) and a GSD of 5 [cm/pixel]:

- supposing that the image height is 4000 [pixels].
- speed of the UAV/plane is 30 [km/h] = 8.33 [m/s].

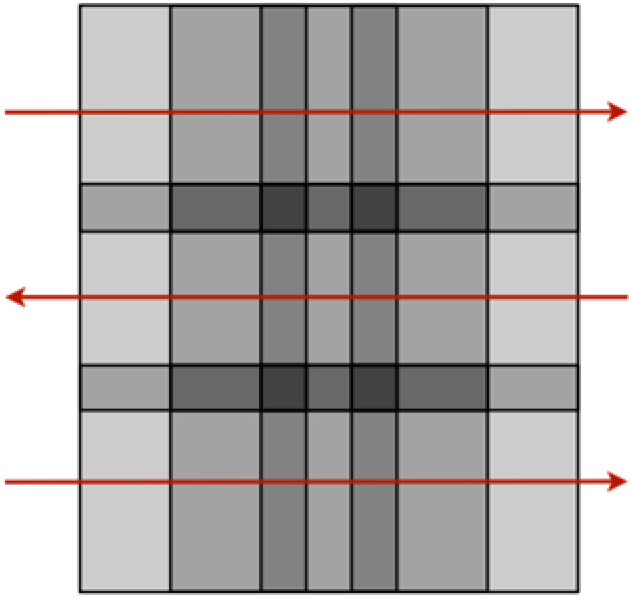
The image rate (t) should be 6 seconds:

*t = ((imH * GSD) / 100) * (1 - overlap) / v = ((4000 * 5) / 100) * (1 - 0.75) / 8.33*
= ***6 [s]***

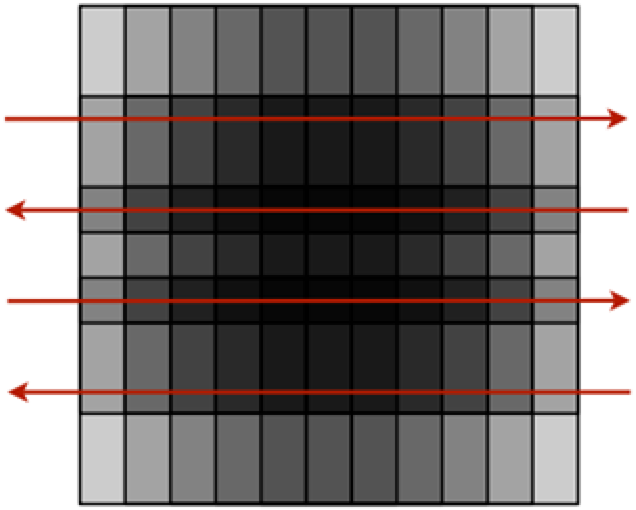
od	*= overlap between two images in the flight direction [m]*
overlap	*= desired frontal overlap between two images [%]*
D	*= ground distance covered by one image in the flight direction [m]*
x	*= distance between two camera positions in the flight direction [m]*
v	*= flight speed [m/s]*
t	*= elapsed time between two images (image rate) [s]*
Dh	*= ground distance covered by one image in the height direction (footprint height) [m]*
imH	*= image height [pixel]*
GSD	*= desired GSD [cm/pixel]*

Image blocks

- Classical block setup
  - 60% along-track overlap
  - 20% cross-track overlap
  - 2-6 observations per point



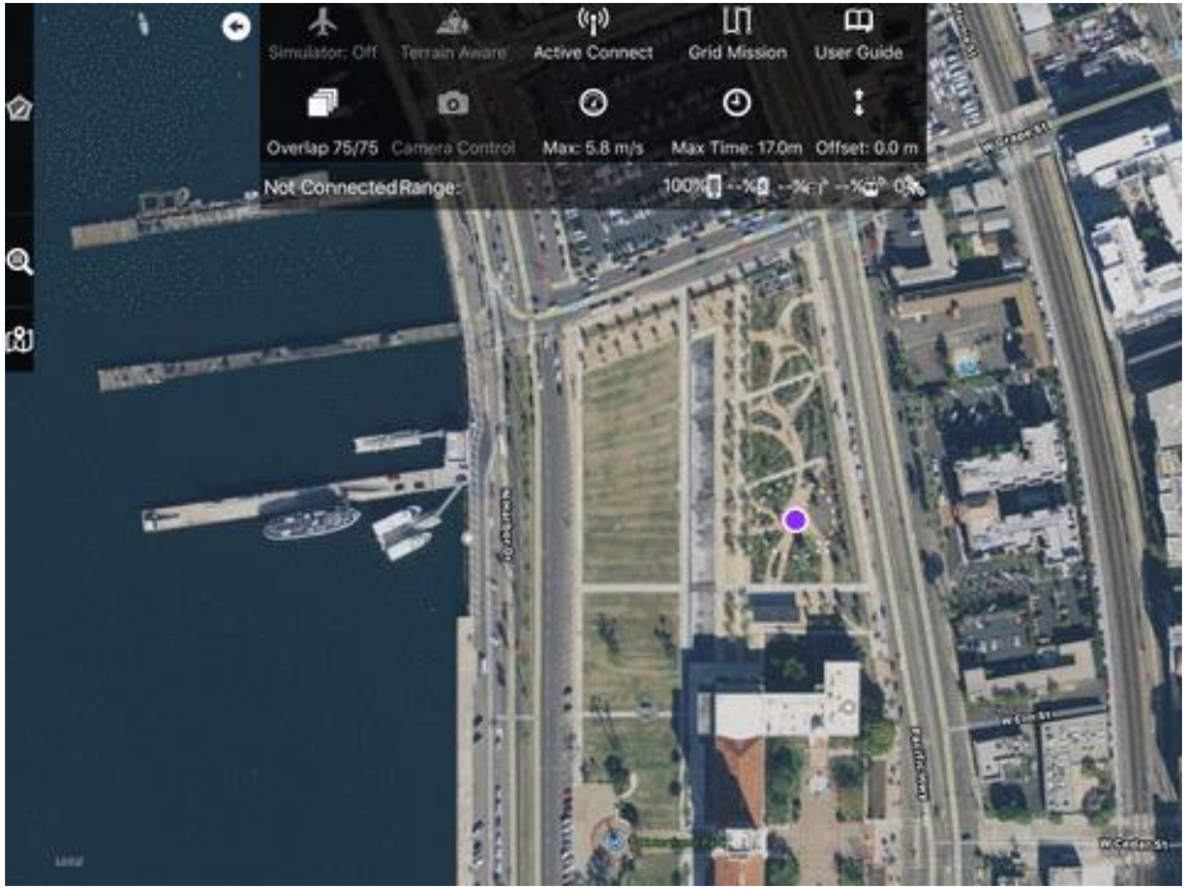
- "Modern" block setup
  - 80% along-track overlap
  - 70% cross-track overlap (or even more)
  - 10-15 observations per point



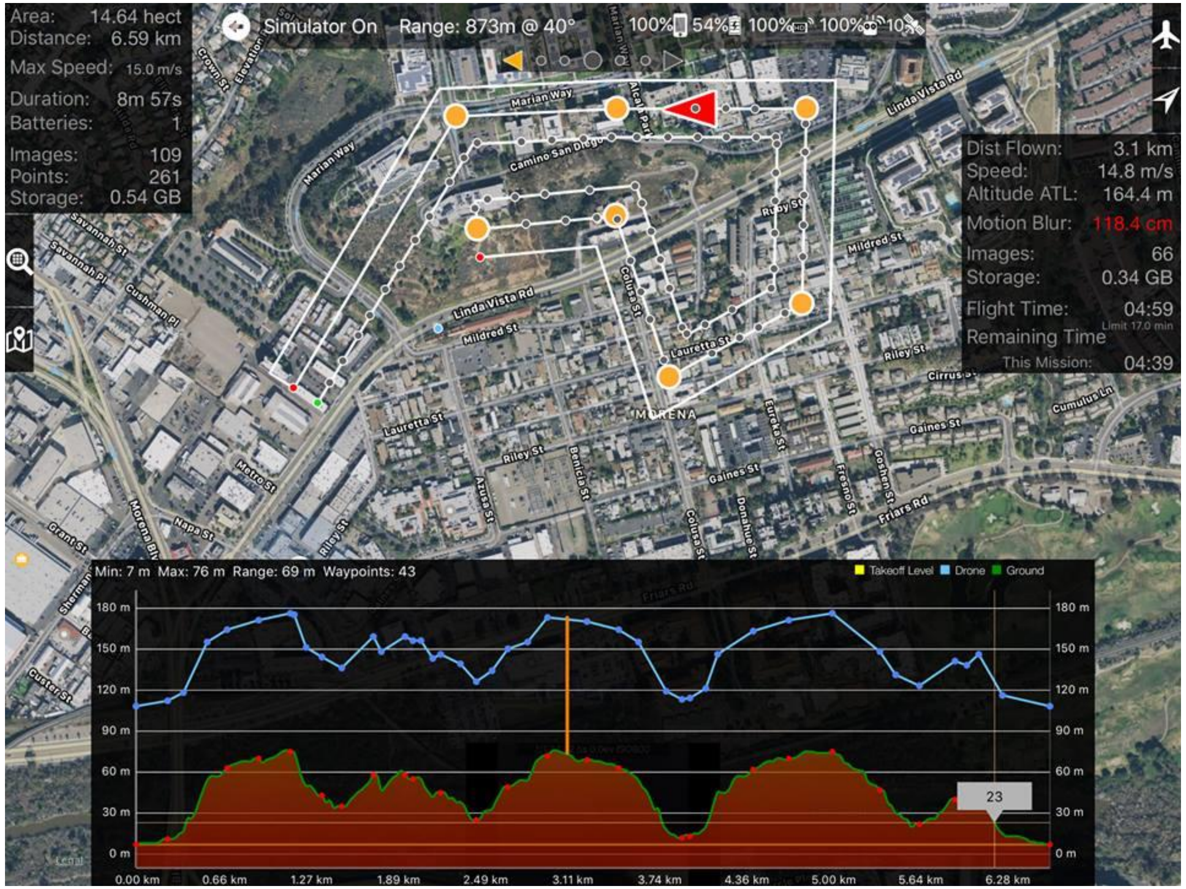
UAV Flight Planning

- As drones combines with GNSS and IMU devices; UAV Flight can be automated
- Todays flight planning software attempts to do as much of the computation heavy lifting as possible so you can worry about the on-site issues and not worry about the tech.
- Combine Features As
    - **Automatic Flight Path Generation and Execution** via waypoints
    - **Terrain Awareness**: Ensure Safe Flight and Constant Overlap
    - Base maps
    - Auto Take-off / Auto Land

UAV Flight Planning - Features



Automatic Flight Path Generation



Terrain Awareness

UAV Flight Planning

- Factors To Be Considered
  - UAVs are flying Low; Beware of Obstacles
  - Very Limited Flight Time

  - Understand the project goals clearly; Plan the mission accordingly
    - Flying Height
    - Image Overlap
    - Camera Selection
    - Flight Grid Placement
  - Clear idea of the area to be surveyed
    - Existing satellite images (Google earth) or aerial images can be used for reconnaissance

Flight Planning Software for DJI Drones

- Map Pilot for DJI: https://support.dronesmadeeasy.com/hc/en-us/categories/200739936-Map-Pilot-for-iOS
- Pix4D Capture: https://pix4d.com/product/pix4dcapture/
- DJI Ground Station Pro: http://www.dji.com/ground-station-pro
- DroneDeploy: https://www.dronedeploy.com/

So far **the BEST** ☺………(Only available for iPad ☹)

Birds Attack!!! Beware

References

- Elements of Photogrammetry with Application in GIS, Fourth Edition
  Book by Bon DeWitt and Paul R. Wolf
- Cyrill Stachnisss' Lecture Notes & videos on Photogrammetry
  https://www.youtube.com/channel/UCi1TC2fLRvgBQNe-T4dp8Eg

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