L02: Photogrammetry and laser scanning

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TERRA
Remote rock mass characterization

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Learning goal

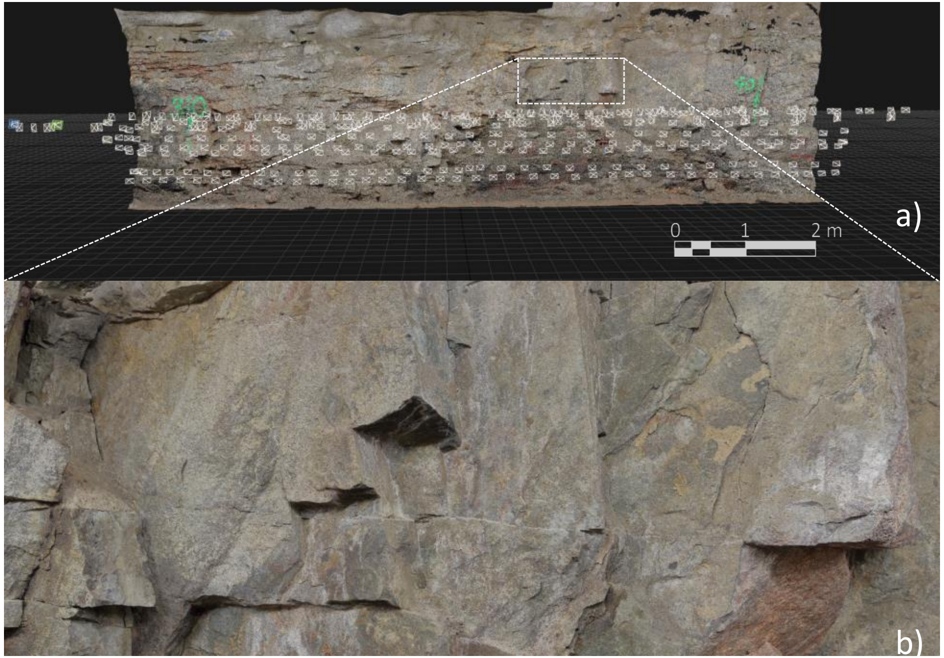
After this session you will be able to:

- understand the basic principles of photogrammetry and laser scanning
- know the differences between photogrammetry and laser scanning
- understand the photogrammetric workflow

Goal of rock mass surface digitization for remote characterization

- Reconstruct a **3D digital model of a rock surface** that **replicates the rock mass** as closely as possible with **accurate geometry** (and color) and **sufficient resolution** so that rock mass properties can be derived from it

- **Good input data is key =>** capture high quality scans/image sequences



Requirements of 3D surface models/point clouds for rock mass characterization

- 1:1 scale
- oriented (N, horizontal plane)
- (georeferenced)
- min. point spacing/density
- (correct color)

Suitability vs Quality

Focus should be on the suitability of the products and not on getting the highest accuracy and resolution

Carefully decide on the requirements of the end product before the acquisition and processing is even started

But, it is always easier to downgrade a high quality product than interpolating low quality

Photogrammetry

History of photogrammetry

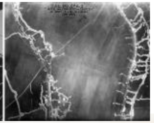
1st: early history

15th century: Leonardo da Vinci, perspective projection

1820s: Niepce & Daguerre invent photography

2nd: analog

1851: French officer Aime Laussedat develops first photogrammetrical devices and methods



3rd: analytical

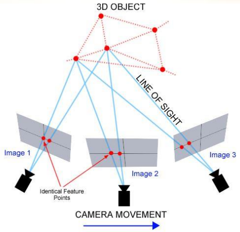
1950-70s: analytical plotter

4th: digital

1979: SfM original idea by Ullman

1999: algorithm that powers the SfM developed by Lowe

2010s- first geoengineering applications of SfM



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Structure from Motion (SfM) photogrammetry

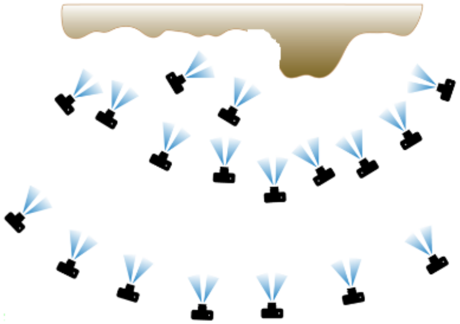
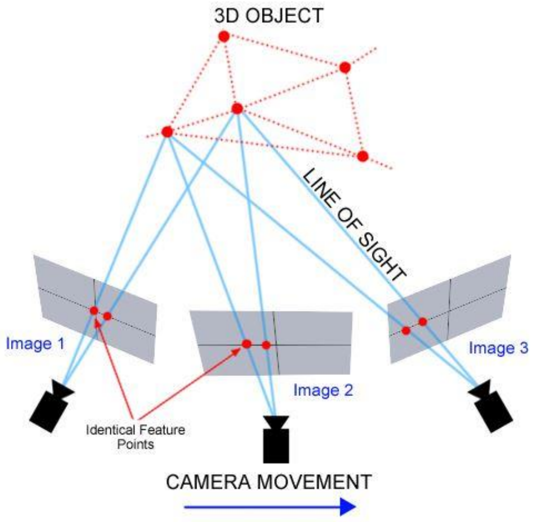


Image acquisition
Control measurement



Feature matching
Image alignment

Dense reconstruction
Texturing

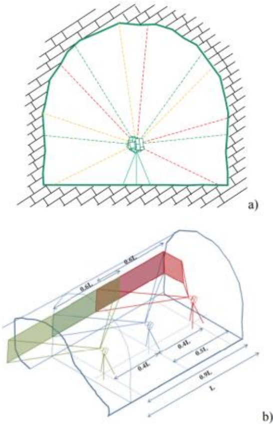
Structure from Motion (SfM) photogrammetry

- Idea originated by Ullman, 1979
- Algorithm that powers SfM developed by Lowe, 1999

Scale Invariant Feature Transformation (SIFT)

First used to generate large point clouds by Snavely et al. (2006; 2007)

First geo eng applications e.g. Roncella et al. 2012



Core skills

- Photography
- Photogrammetry
- Surveying
- Software
- Data processing
- Visualization

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Basic procedure

Image capturing

A series of overlapping images is taken

→

Image matching

Tie points are matched, and camera orientations estimated

→

Dense point cloud generation

A dense cloud is generated, consisting of all matches

→

Secondary output generation

Ortho-images

DEM

Textured mesh

→

Data analysis and/or visualization

What?

objects that are **not suitable** for photogrammetry:

strong reflections

transparent

moving

objects that are **suitable** for photogrammetry:

static, solid, rough

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When?

Outdoor: Weather is the most important factor to consider

Worst = rain and snow + wind

- surfaces can be moving
- reflection is stronger

Best = cloudy but bright, no wind

Indoor: lighting, dust

Where?

carefully plan the shooting trip

- choose a location to capture the images
    - Is it safe?
    - Is the object visible?
    - Is it meeting the requirements? (calculate pixel size/GSD)
- minimize the amount of travel and prevent wasted time
    - Don't be afraid to take too many images
    - Record a video if not sure about full coverage

Photogrammetric project workflow

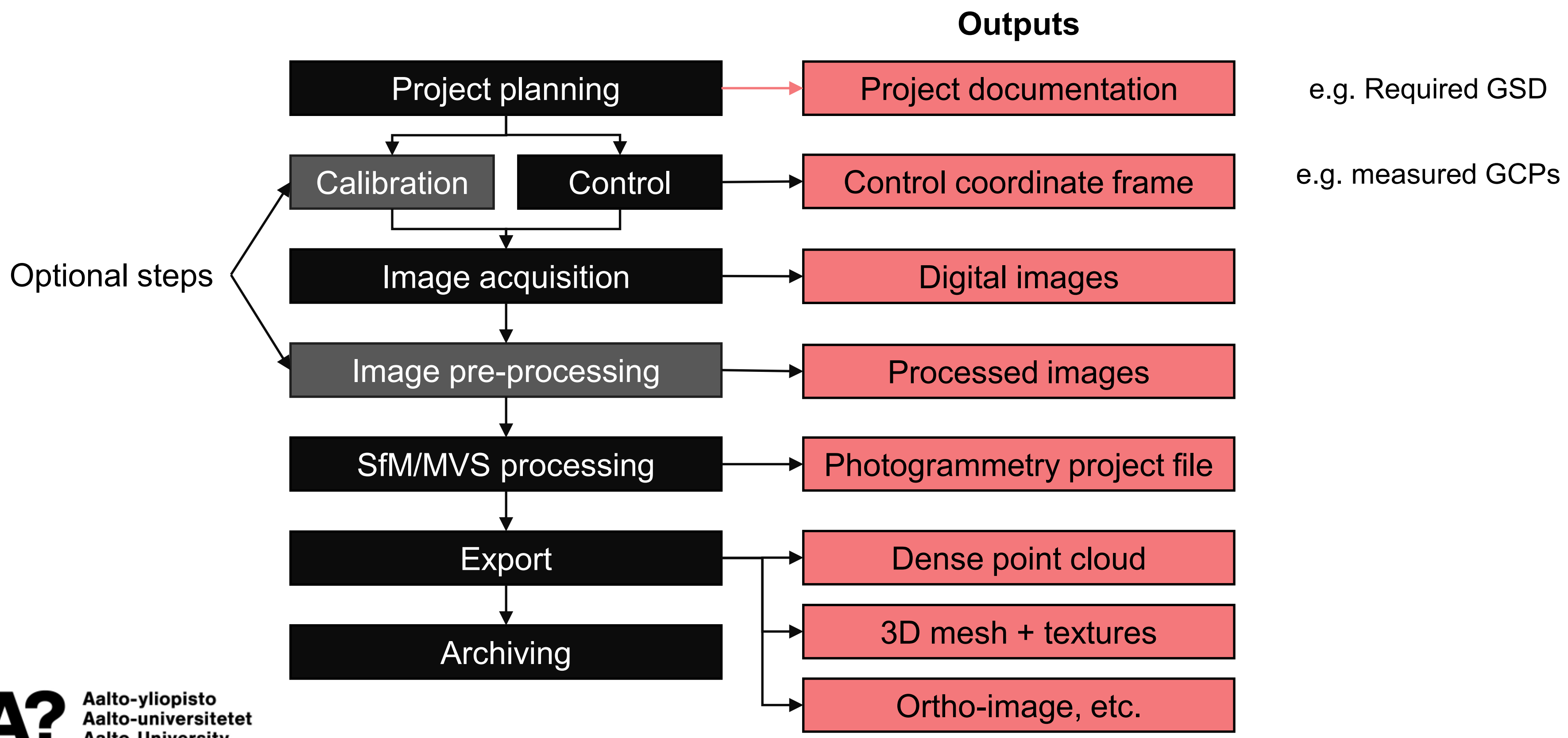

Image aquisition hardware

- most cameras work but use DSLR or mirrorless camera for best quality
- model resolution governed by pixel size/resolution => high megapixel sensors preferred
- good lens with low distortion => fixed focal length lens (prime)
- recently software also handles high distortion cameras, e.g., 360, actions cameras

Resolution and sensor size

Sensor name	Dimensions (mm) (approx.)	Area (mm^2) (approx.)	Percentage of 35mm full-frame (approx.)	Typical cameras and approx resolutions (mega-pixels, MP)
35mm full-frame	36×24	864	100	Nikon D3X (24MP), D800 (36MP) Canon EOS 5D mark III (22.3MP) Leica M (24MP) Sony Alpha 7R II (42.4MP)
APS-H	28.7×19.1	548	63.45	Canon EOS 1D (inc. marks II–IV) (8.2MP for mark II)
APS-C (Nikon DX)	23.6×15.7	370	43	Nikon D300 (12.3MP), D3000 (10.2MP), D7100 (24.1MP), D80 (10.2MP), D70 (6.1MP)
APS-C (Canon)	22.2×14.8	329	38	Canon EOS 7D (20.2MP), EOS 60D (18MP), EOS 50D (15.1MP)
4/3"	17.8×10	178	20.6	Panasonic Lumix DMC-L10 (10MP) Olympus E5 (12.3MP) Leica Digilux 3 (7.5MP)
1/1.7"	7.6×5.7	43	5	Canon Powershot G12 (10MP) Ricoh GR (16.2MP) Nikon Coolpix P7100 (10MP) Panasonic DMC-LX5 (10MP)
1/2.3"	6.2x4.6	28	3.25	Sony Cybershot DSC HX50

most cameras work but use DSLR or mirrorless camera for best quality

- model resolution governed by pixel resolution => high megapixel preferred
- good lens with low distortion => fixed lens
- recently software also handles high distortion cameras

Pixel size (=GSD)

Image credit: Future

1. Focal length	24		mm
2. Format size	Width	36	mm
	Height	24	
2b. Format size preset	Full frame 35mm		
3. Distance of camera to object	10		meters
4. Allowable coverage	100%		
5. Resolution (optional)	61		mega-pixels
Computed coverage	Width	**15.00**	meters
	Height	**10.00**	
Computed pixel size	**1.568**		millimeters
manual marking=2x	**3.136**		
subpixel=1/20th	**0.078**		
dot-size=8x	**12.545**		

https://www.photomodeler.com/pm-support/field-of-view-calculator/

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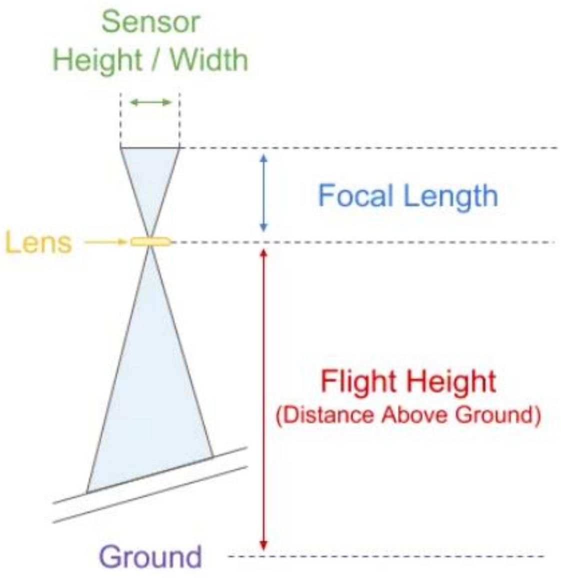
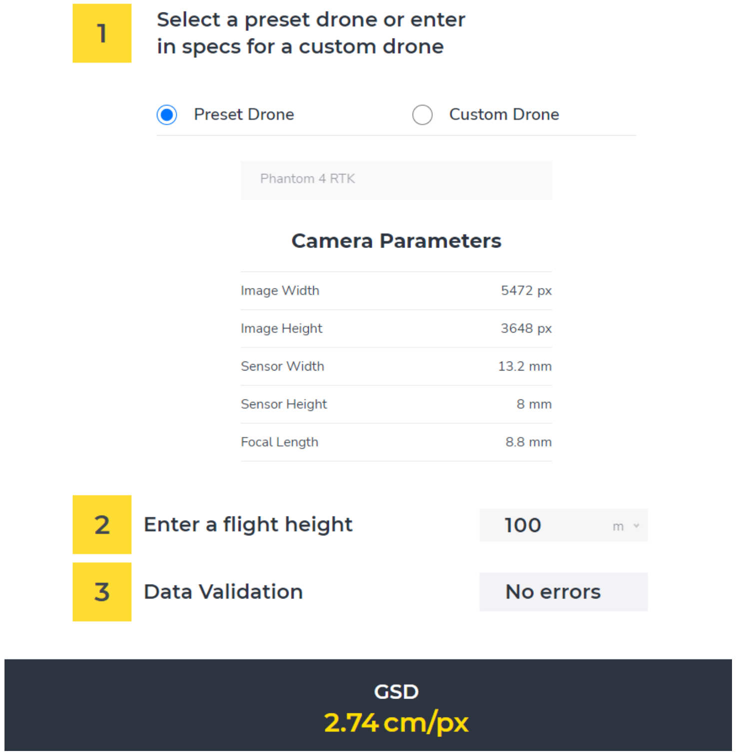
Ground Sampling Distance GSD



$$GSD_h = \frac{Flight\ Height * Sensor\ Height}{Focal\ Length * Image\ Height}$$

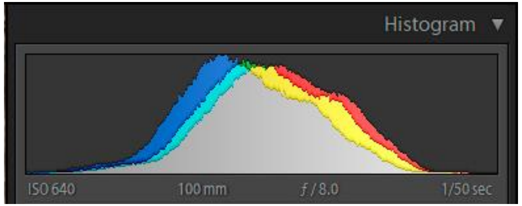
$$GSD_w = \frac{Flight\ Height * Sensor\ Width}{Focal\ Length * Image\ Width}$$

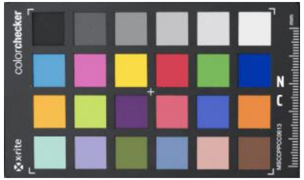


https://www.propelleraero.com/blog/ground-sample-distance-gsd-calculate-drone-data/

Lighting

- Flat lighting is preferred: under-/overexposing results in poor reconstruction
- Use ambient lighting only if possible
- Avoid significant changes in lighting conditions
- If external lighting is used, light the scene evenly with soft light (diffused)
- Use constant white balance (WB)
- Use color reference cards if color reproduction is important





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Basic camera settings

The default recommended settings => aim to have the sharpest image possible with correct exposure:

- manual M mode or aperture priority A
- aperture f/8 or smaller
- Low ISO 100 – 400
  - low lighting conditions: first increase the ISO, then the aperture
- Shutter speed to get sharp images
  - Handheld: 1/(2*focal_length)
  - Tripod recommended for low light

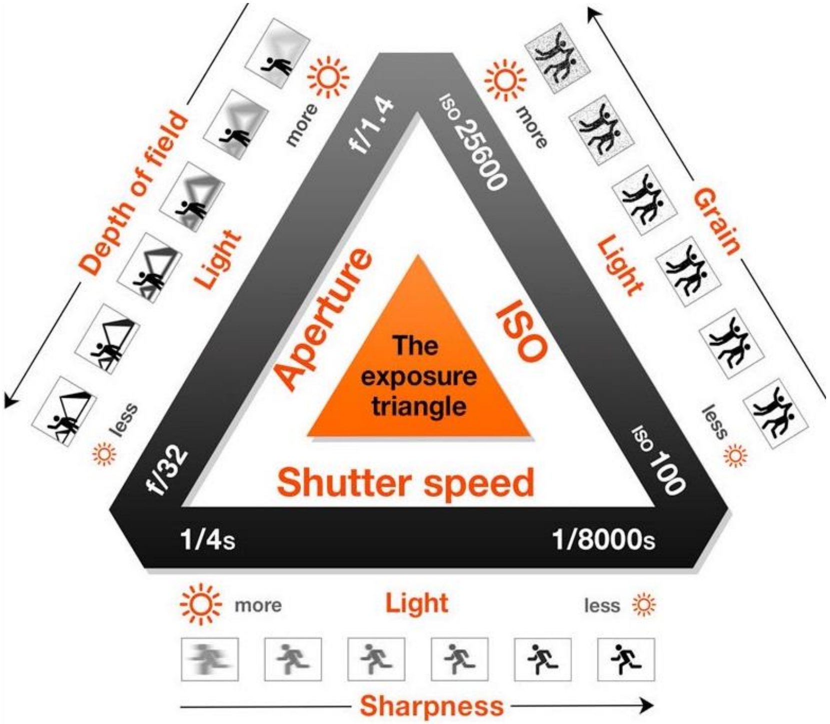
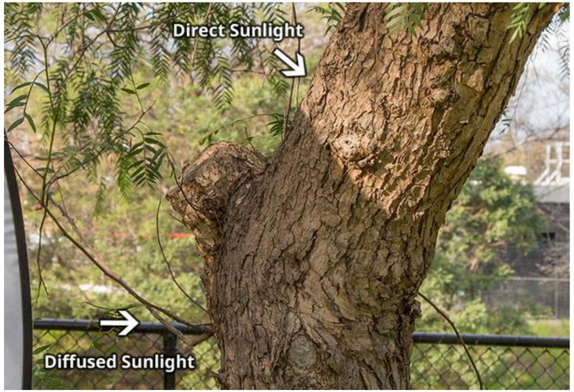


Image source: petapixel.com

Good vs bad images

Harsh lighting

Camera shake



Uneven lighting

Variable lighting conditions

Image source: https://www.vertexlibrary.com/guide-to-3d-scanning-outdoor-photogrammetry-tips

Camera calibration

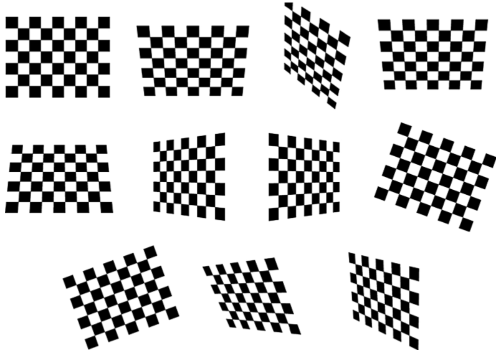
To calibrate or not?

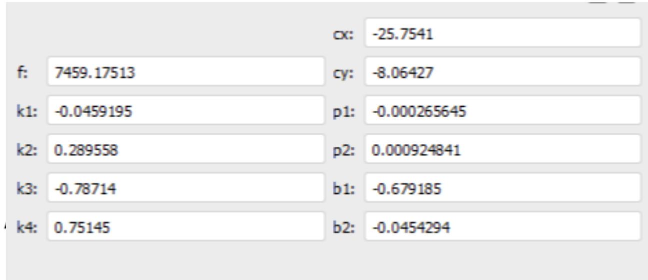
Lens distortion

Checkerboard or point pattern

Calibration software

- In photogrammetry software, e.g. **Agisoft Metashape,** or pre-calibration in other software e.g., **iWitness**





		cx:	-25.7541
f:	7459.17513	cy:	-8.06427
k1:	-0.0459195	p1:	-0.000265645
k2:	0.289558	p2:	0.000924841
k3:	-0.78714	b1:	-0.679185
k4:	0.75145	b2:	-0.0454294

f - Focal length measured in pixels (in pixels)
cx, cy - Principal point coordinates, i.e. coordinates of lens optical axis interception with sensor plane (in pixels)
b1, b2 - Affinity and non-orthogonality (skew) coefficients (in pixels)
k1, k2, k3, k4 - Radial distortion coefficients (dimensionless)
p1, p2 - Tangential distortion coefficients (dimensionless)

Control

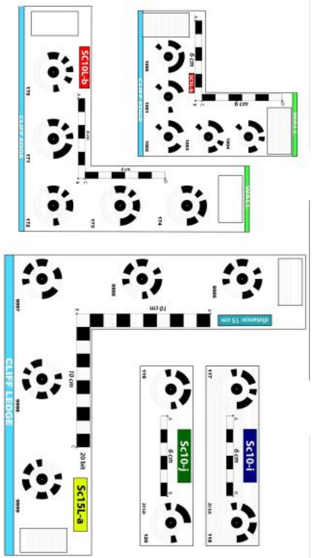
Externally measured points around the object – known coordinates

Used to refine, scale, orientate, and check accuracy

- Scaling: at least 2 control points (scale bar)
- Scaling and orientation: at least 3 points (visible in at least 2 images; 2 xyz)
- Refining image alignment: more than 3 xyz points

Number of control points depends on topography (e.g. 6-10 in relatively flat terrain, >10 in varying topography)

Keep them evenly distributed across the area (near the edges and centrally, top and bottom elevation)



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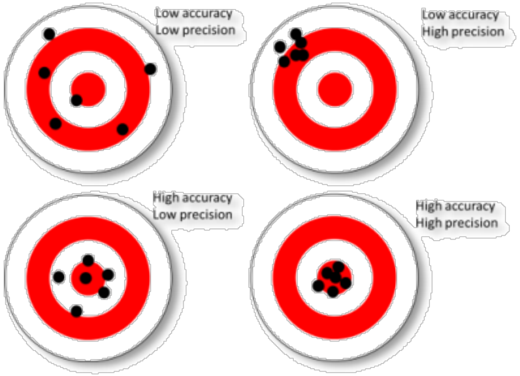
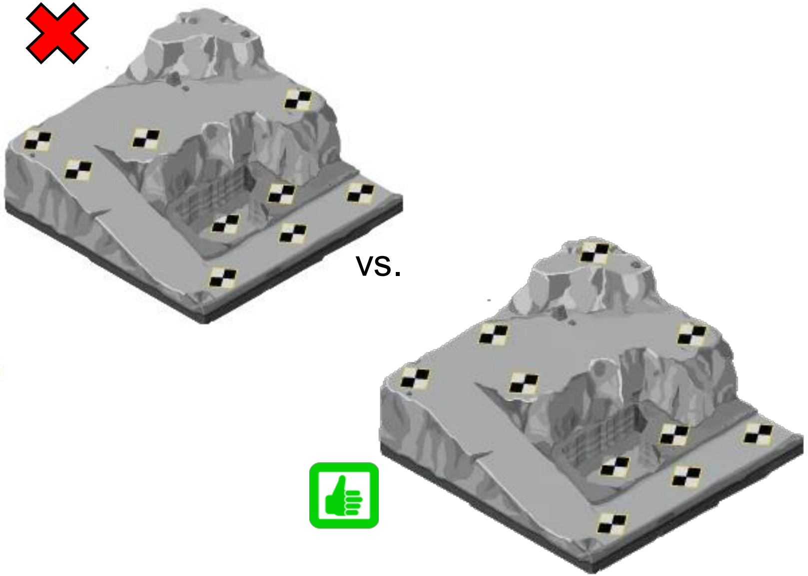
Ground control points GCP



- Internal GPS in drones = positional error ~5m
- GCPs required to get more accurate models
- Placed before the scan and measured
- at least 10 GCPs
- Simple vs. smart ground control points
- RTK systems (e.g. Phantom 4 RTK) provide better accuracy (~cm) but also require GCPs!



https://www.propelleraero.com

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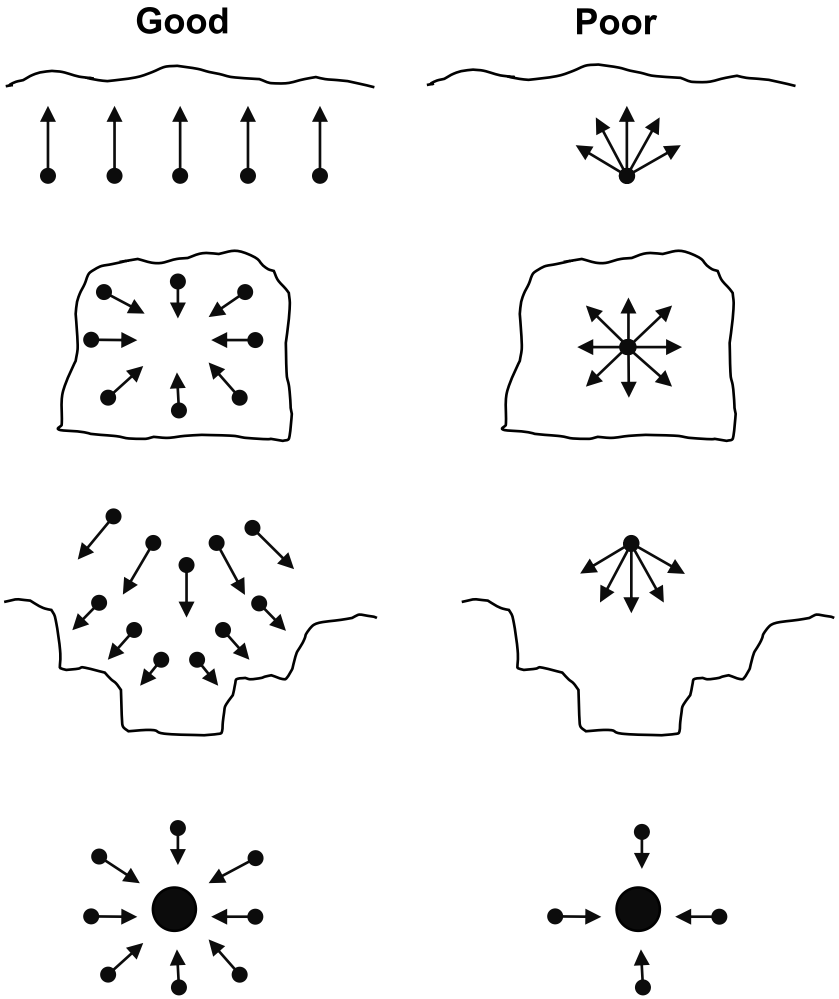
https://support.pix4d.com/hc/en-us/articles/202558699

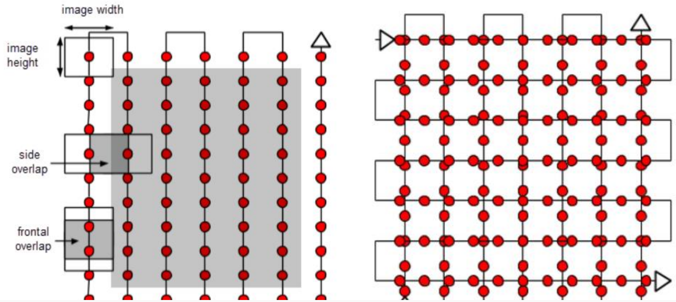
Capturing process

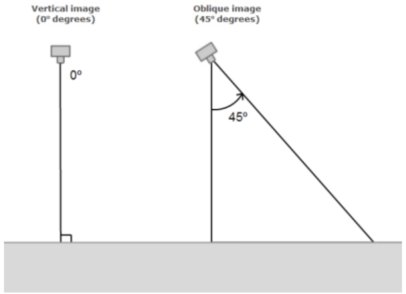
- cover the object fully with sufficient overlap (>60%)
- move around the object and take many far shots, and some fewer close shots to provide more details
- in practice it can be difficult to follow an ideal path

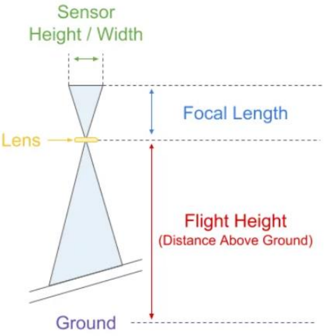


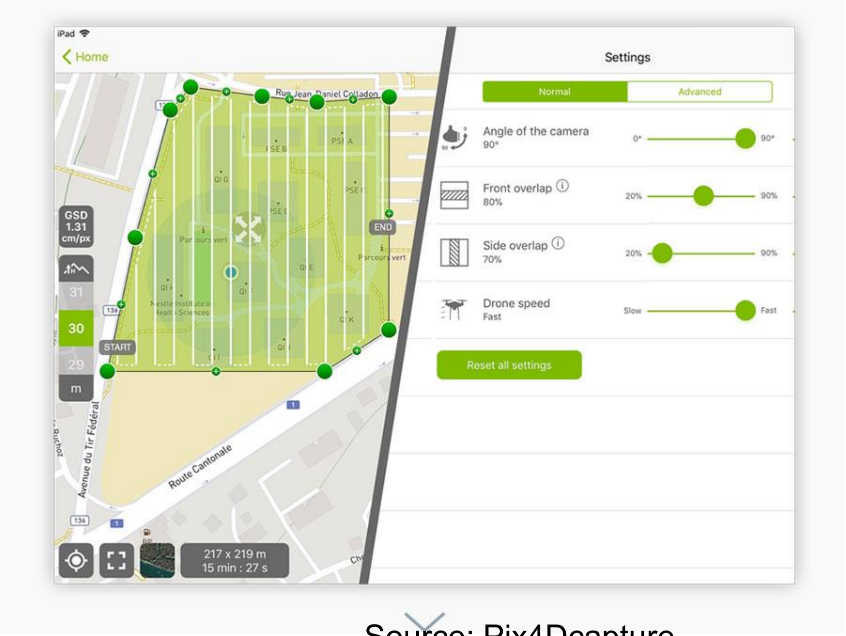
Aerial workflow for large areas

- > 70% image overlap, single and double grid
- Nadir (down-facing) and oblique photos
- Ground Sampling Distance GSD
- Manual or automatic flight path
- Flight planner apps: **Pix4Dcapture**, **UgCS**, **DJIFligthPlanner**



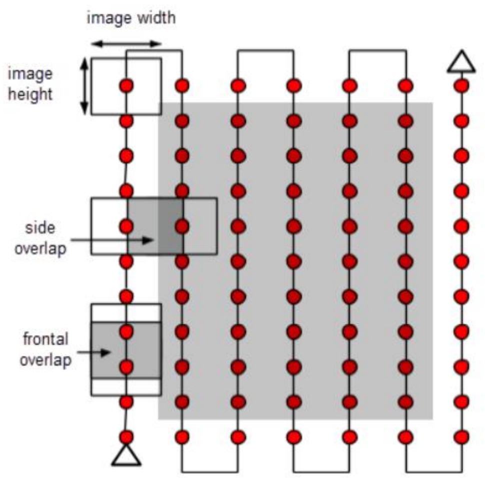


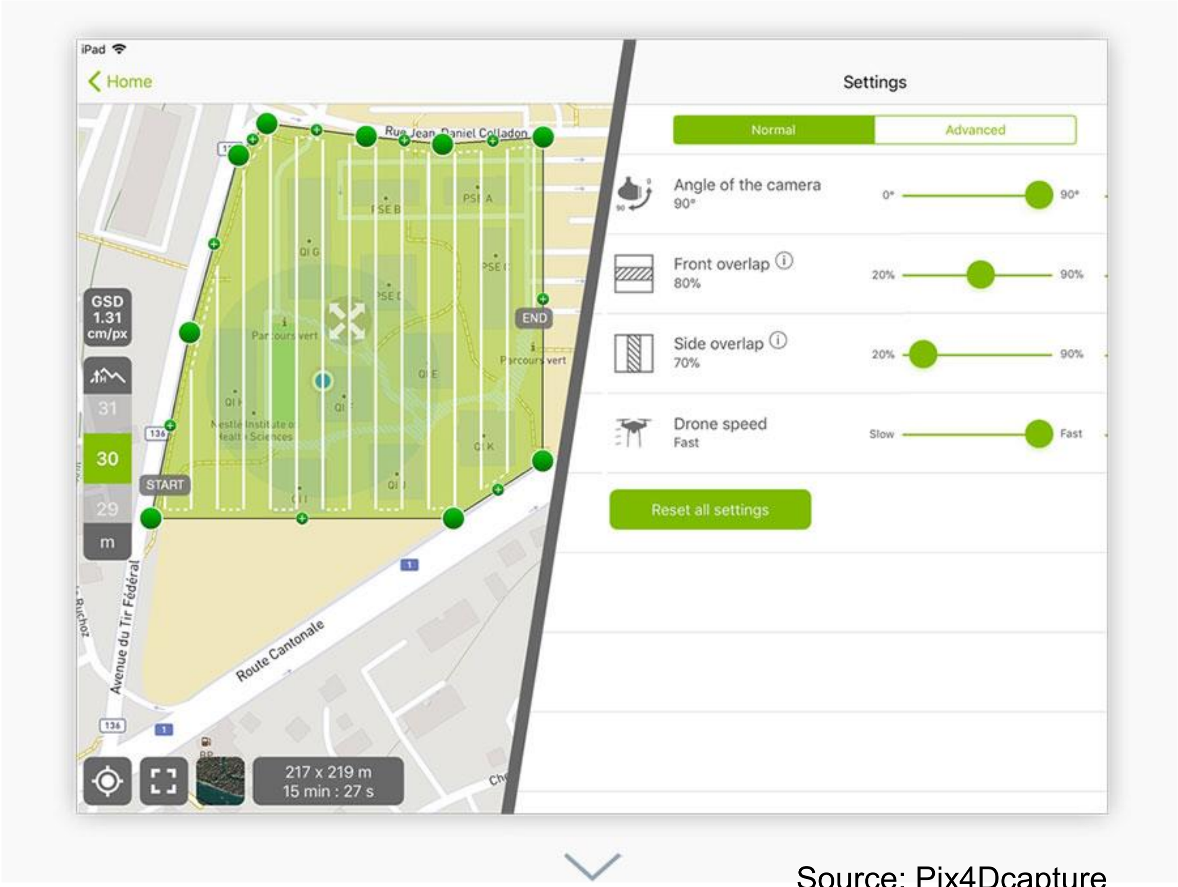




Source: Pix4Dcapture

Flight path

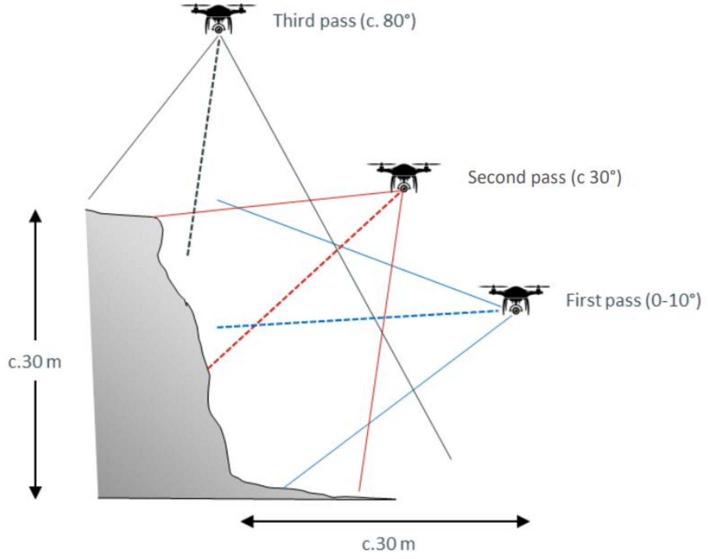




Source: Pix4Dcapture

Slope scanning workflow

- 3 passes at varying angles
- Maintain a constant distance from the slope
- At least 60% overlap
- Don’t be afraid to take too many photos
- Avoid shadows and changing light conditions
    - Best case: bright cloudy day
    - Worst case: sun directly behind or above the slope



Howell et al. 2021. Acquisition of Data for Building Photogrammetric Virtual Outcrop Modelsfor the Geosciences using Remotely Piloted Vehicles (RPVs)

SfM/MVS processing – Hardware and software

- powerfull GPU
- at least 16 GB RAM
- fast hard drive (SSD, M2 NVME)

Software

- RealityCapture
- Agisoft Metashape
- Pix4D
- Recap Pro
- Bentley ContextCapture
- 3DF Zephyr
- PhotoModeller
- Visual SFM
- Meshroom

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RealityCapture

- Tutorials: https://www.capturingreality.com/RealityCapture-Tutorials
- **Requires NVIDIA GPU!**
- **Zoom poll**: Do you have a computer with NVIDIA GPU?

Image source: https://www.youtube.com/watch?v=sak-6Ct-Cdk

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Photogrammetry software workflow

1. Add all images
2. Detect/Add control points + set scale
3. Align
4. Check control and realign if needed
5. Create the model
6. Colorize or texture
7. Export

Detailed workflow in
E02: 3D data processing

Error sources

- **Instrumental** (optical distortion)
- **Object-related** (material, moisture)
- **Environmental** (atmosphere, lighting conditions)
- **Methodology (**operator, hardware, software, camera network, control measurements)