Pix4D Training

July 2013

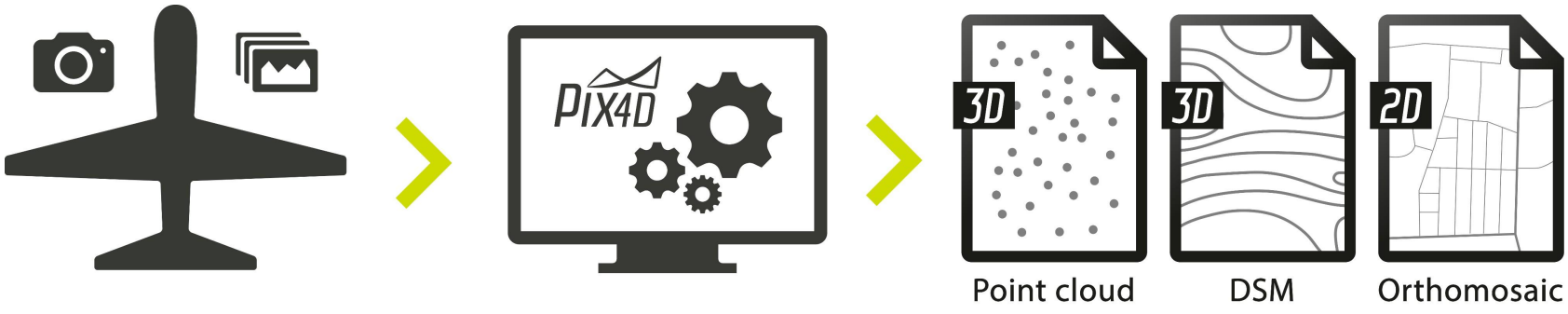
Plan

- Intro
- Stereoscopy/calibration theory
- Processing steps
  - Step1: Calibration
  - Step2: Point densification
  - Step3: DSM and orthomosaic
- Output files usage
- Software quick guide

Introduction

Pix4D converts thousands of images into

- 3D Point Cloud
- 3D Digital Surface Model
- Orthomosaic



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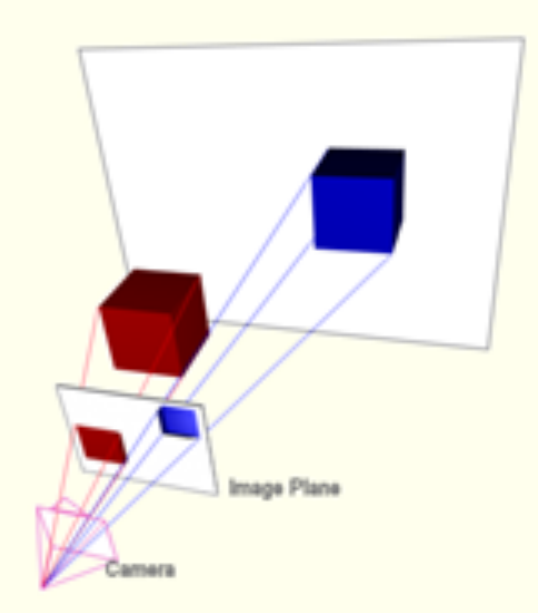
From 2D to 3D

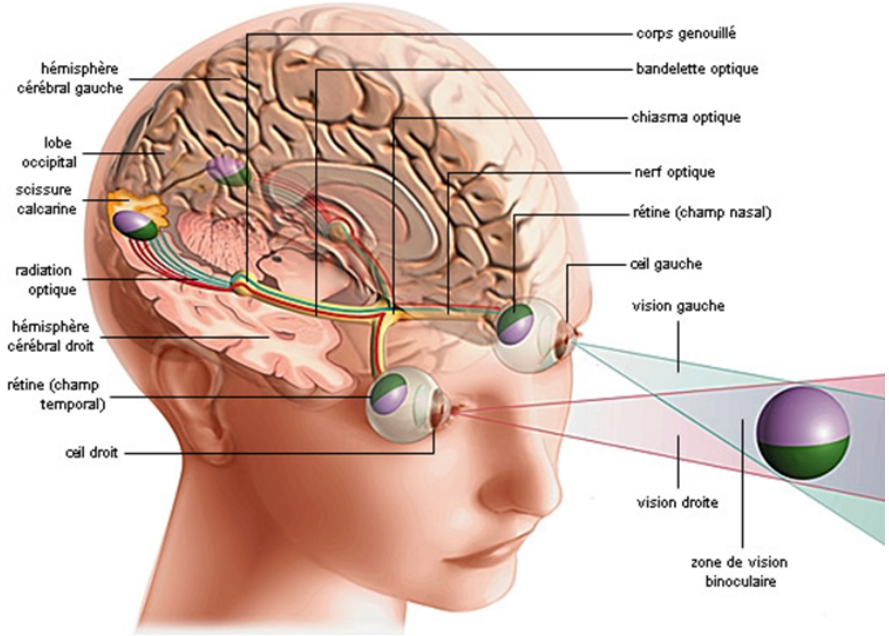
From 3D to 2D

<u>One camera</u>
Far appears smaller than near on image

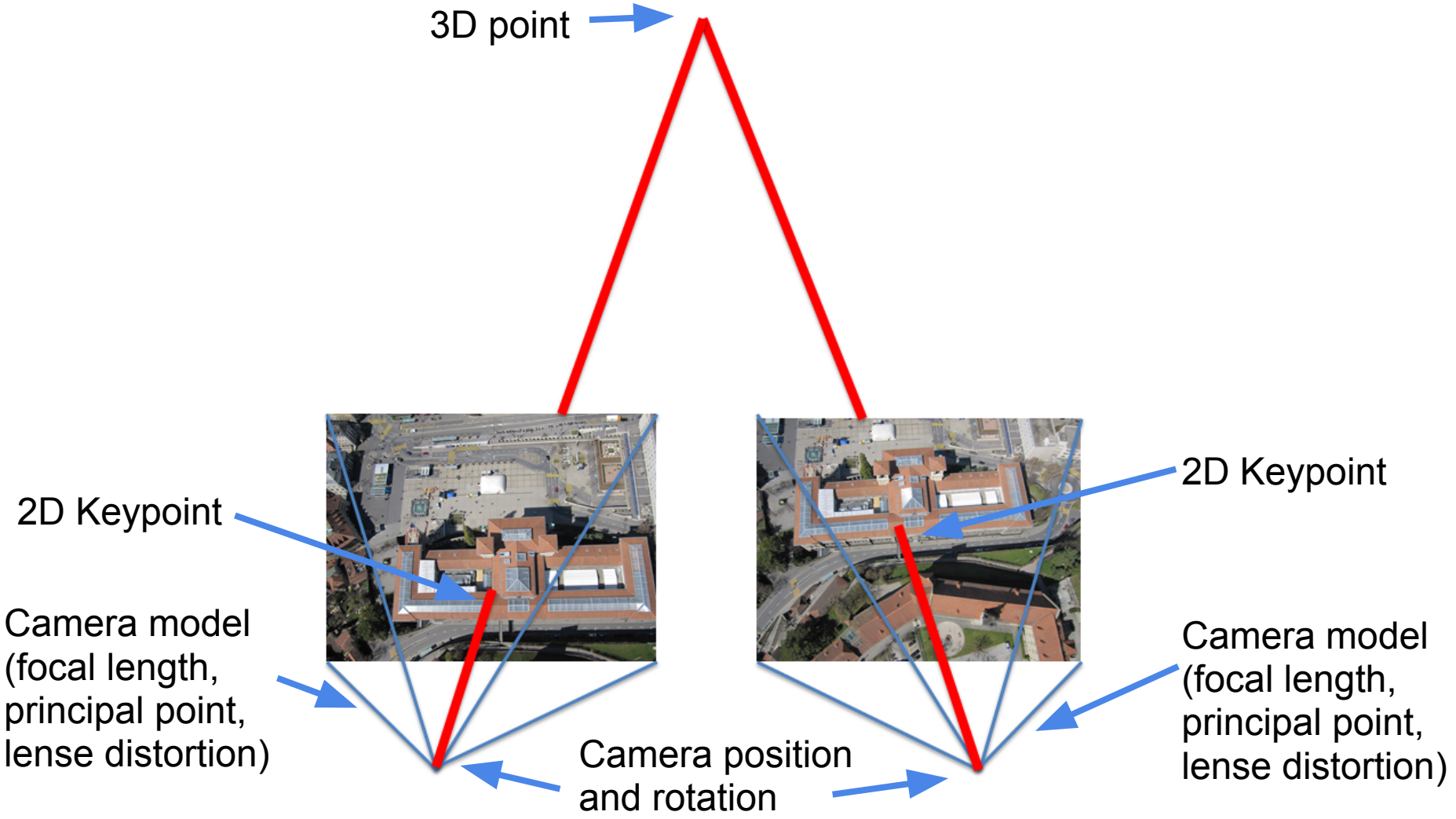


From 2D to 3D

<u>Two images</u>
Triangulate to get sense of depth



From 2D to 3D: Stereoscopy



Camera calibration

Exact camera model and position needed for reconstruction

GPS tag not precise enough (1-10 meters)

Pixels contain geometrical information about the exact camera position (1-10mm)

Calibration is about computing exact camera position/rotation/model from pixels alone

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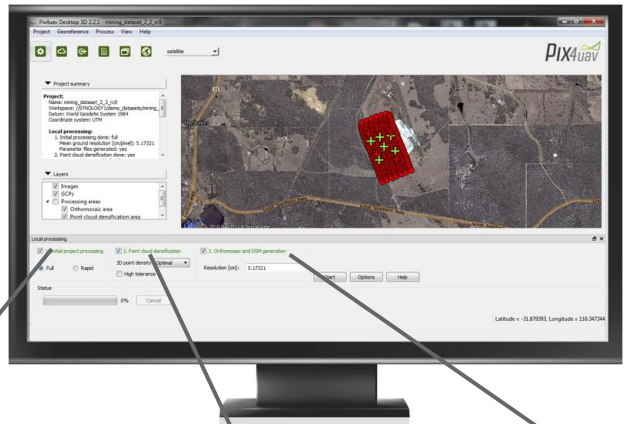
3 main processing steps



Step 1: initial processing

Images
=> calibrate cameras

Step 2: point densification

Calibrated cameras
=> point clouds

Step 3: DSM and orthomosaic

Point clouds
=> DSM and orthomosaic

Keypoint extraction
Keypoints matching
Camera model optim
Geolocation GPS/GCP
Point densification
Point filtering
DSM generation
Orthomosaic images
Orthomosaic blending

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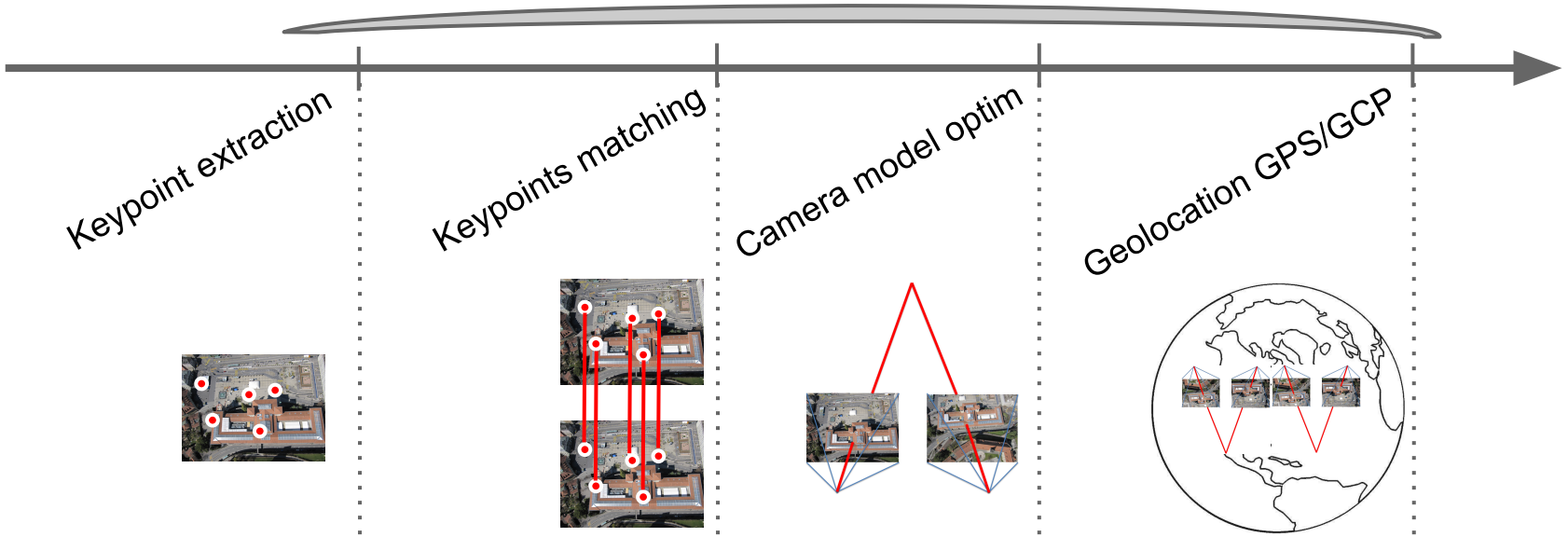
Camera calibration

Step 1: initial processing

Images => calibrate cameras



Example:

60'000 keypoints per image

Average of 6'000 matches per pair of images

600'000 matches => 150'000 3D Points for 100 images project

Average of GPS OR Min 3 GCP

Camera calibration

1. **Extract keypoints**
   a. interesting areas, high contrast
   b. create "signature" based on surrounding image content
2. **Match keypoints**
   a. Find neighboring images using GPS
   b. Match all keypoints between these images
3. **Camera model**
   a. Fit a camera model to the matched keypoints
   b. Triangulate matches to make 3D points
   c. Optimize camera model and keypoint matches
   d. Add more images (and keypoints), and repeat
4. **Geolocation**
   a. Use GPS tags average for approximate geolocation
   b. Use GCP for precise geolocation

Extract Keypoints

Good image:

- rocks,bushes,dirt
- buildings, urban
- more than 10MP
- extract > 10'000 keypoints


Difficult images:

- sand, snow, fog
- blurry, out of focus
- Overexposed, underexposed
- less than 3MP
- extract < 100 keypoints





Match keypoints

Easy to match

- images with high # keypoints
- images with high overlap


Hard to match

- images with low # keypoints
- trees at low altitude
- extreme angle with no transition
- low overlap



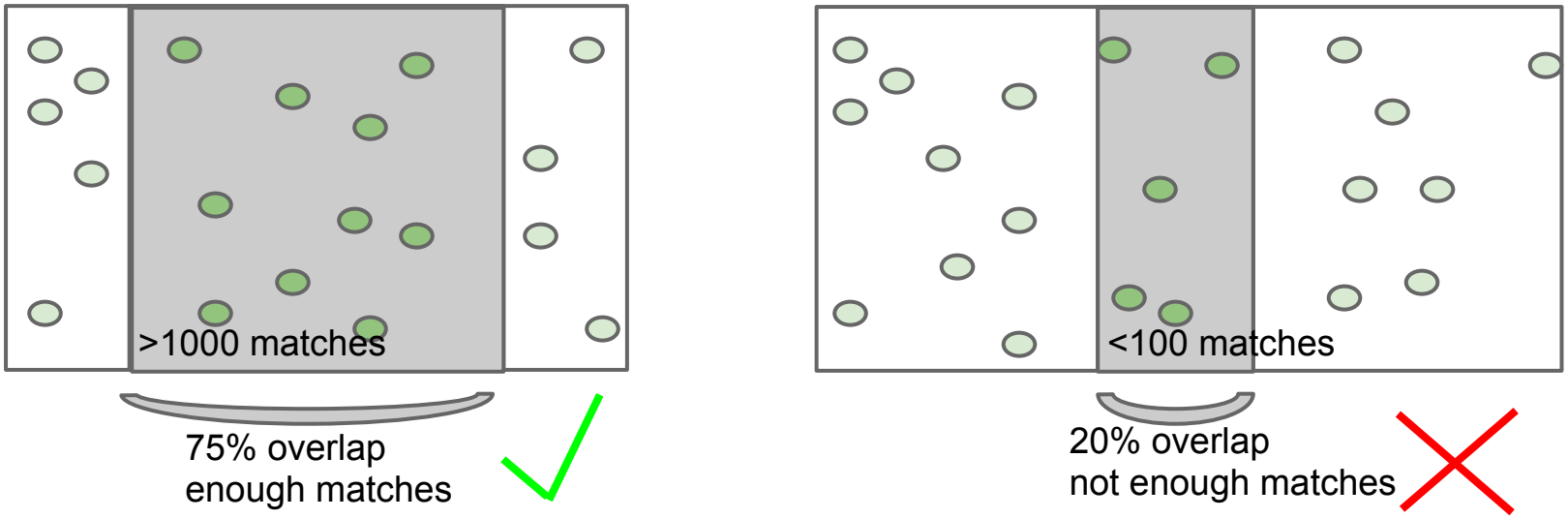

Impossible to match

- Reflective surface like water
- Moving objects


Getting enough matches

Enough matches:

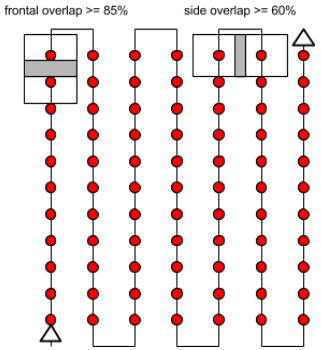
- # matches > 1000 per image pair
- Depends on overlap, image size and visual content
  - If small image size => more overlap required
  - If low visual content => more overlap required
- Images of 12 MP => 75% overlap recommended in most cases



Flight plan

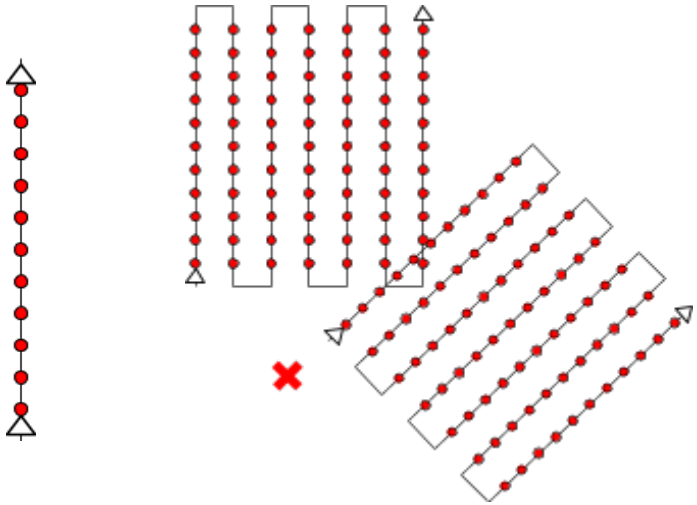
Ideal flight plan

- regular grid flight plan
- easy terrain: 75% frontal, 50% side
- difficult terrain: 85% frontal, 60% side



Difficult flight plan

- low overlap
- multiple images at same location
- corridor mapping
- high difference in altitude (>2xGSD)

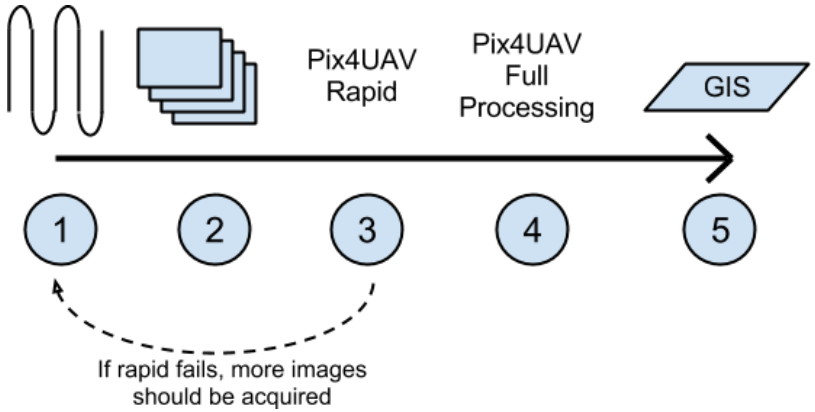


Camera Calibration: quality report

Quality Check

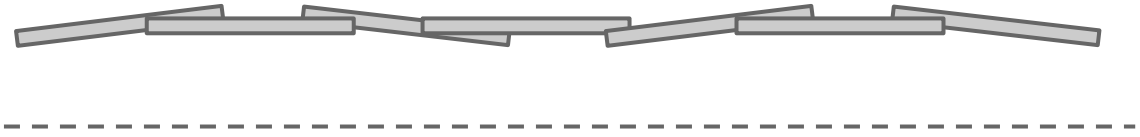
Images:	median of 26453 keypoints per image	✓
Dataset:	70 out of 70 images calibrated (100%)	✓
Camera optimization quality:	1.56% relative difference between initial and final focal length	✓
Matching quality:	median of 4377 matches per calibrated image	✓
Georeferencing:	12 GCPs, 0.026 [m]	✓

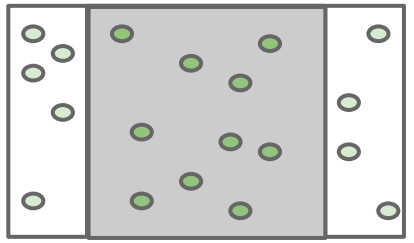
- Ensures quality of project
- **Issues with project**
  - **To solve 99% of issues: Increase overlap or fly again**
- Proposed workflow



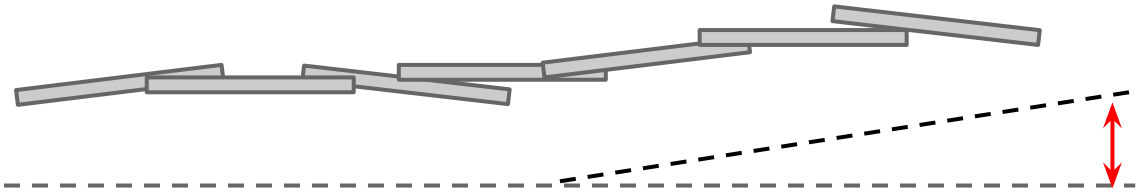
Camera calibration: accuracy

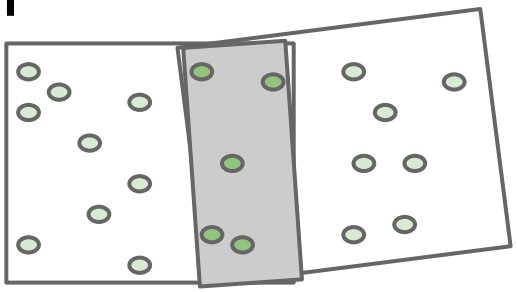
Good calibration





Error in calibration: error propagation





Sufficient matches prevent calibration errors

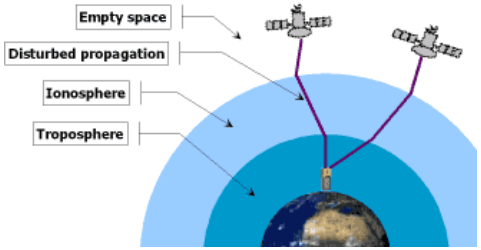
(> 1000 matches/image)

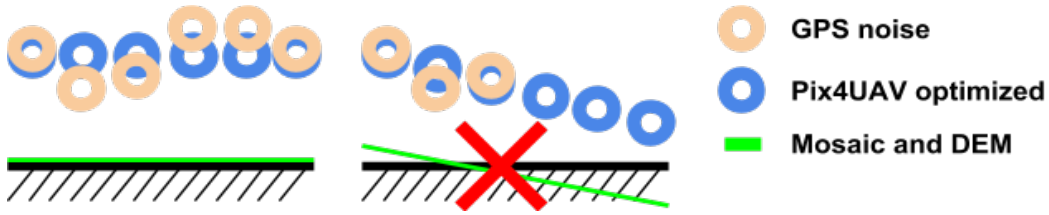
Georeference

Project size, orientation and position unknown

GPS tags

- approximate position,orientation,size
- good synchronisation, high number of GPS tags => better approximation
- ~20 meter shift in random direction





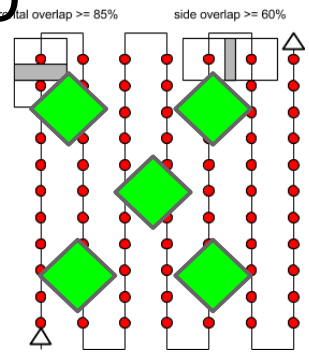
GCP

- If GCP, GPS tags are not used
- Minimum 3 GCPs
- Results in same coordinate system as GCPs

Geolocation: accuracy

GCPs

- well distributed in dataset, measured below GSD
- 5-8 usually enough for 1000 images
- Quality report shows reprojection error



- Good calibration + GCP: error at most 1-2 times the GSD

Verification points

- Error is minimized at GCPs: not optimal to assess global accuracy
- Verification points are not used during optimization

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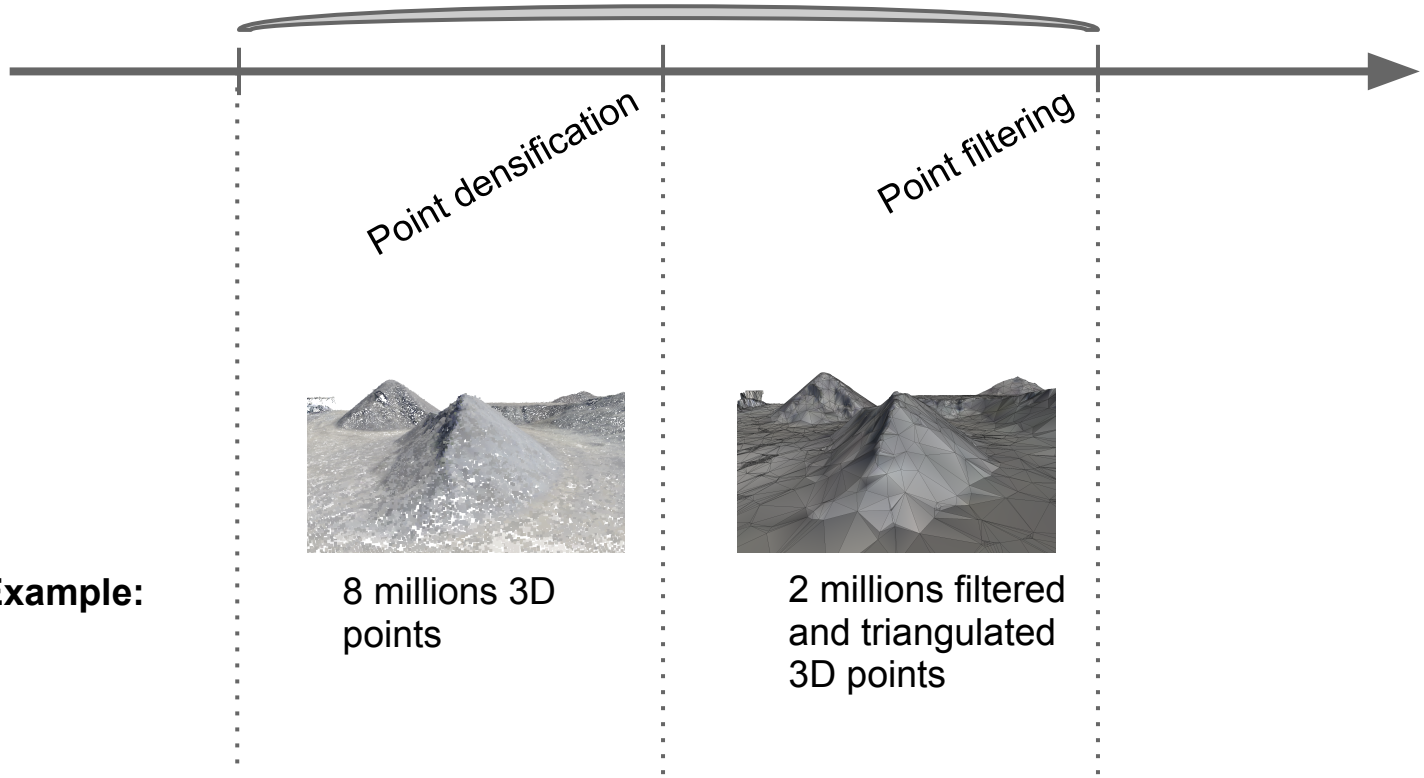
Point densification

Step 2: point densification

Calibrated cameras => cloud of points



Example:

8 millions 3D points

2 millions filtered and triangulated 3D points

Point densification

Visual content

- 3D points computed where there is visual content
  - There may be "holes" in point cloud
  - No visual, no 3D (example: no ground under trees)
- Roads, rooftops, may contain little visual content
  - Less visual => less accuracy/less points

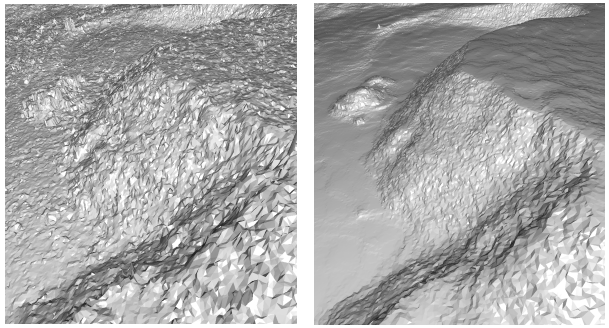
Scale

- Trees visual content only at lower resolution
  - Use "high tolerance" to model trees
  - Expect lower accuracy at trees

Point densification: filtering

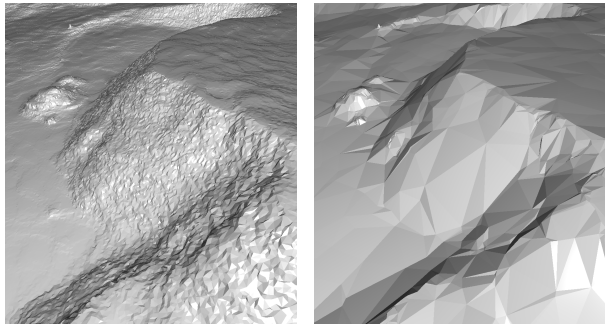
Noise filtering

- improves quality
- 2.5D only



Smoothing

- removes redundant points
- makes point cloud easier to manage (smaller files generated)
- 2.5D only



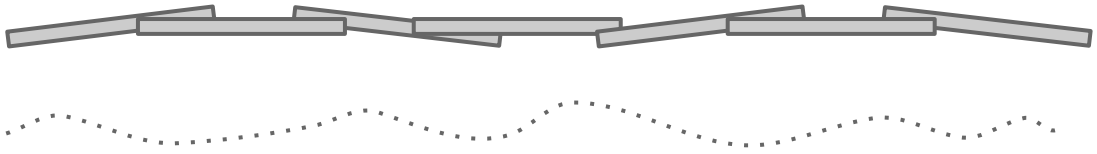
Point densification: accuracy

Point cloud accuracy

- Good camera: error at most 1-2 times the GSD
- up to 3 times the GSD at areas with low visual content

Global Accuracy

- Calibration+Georeference+Point Cloud



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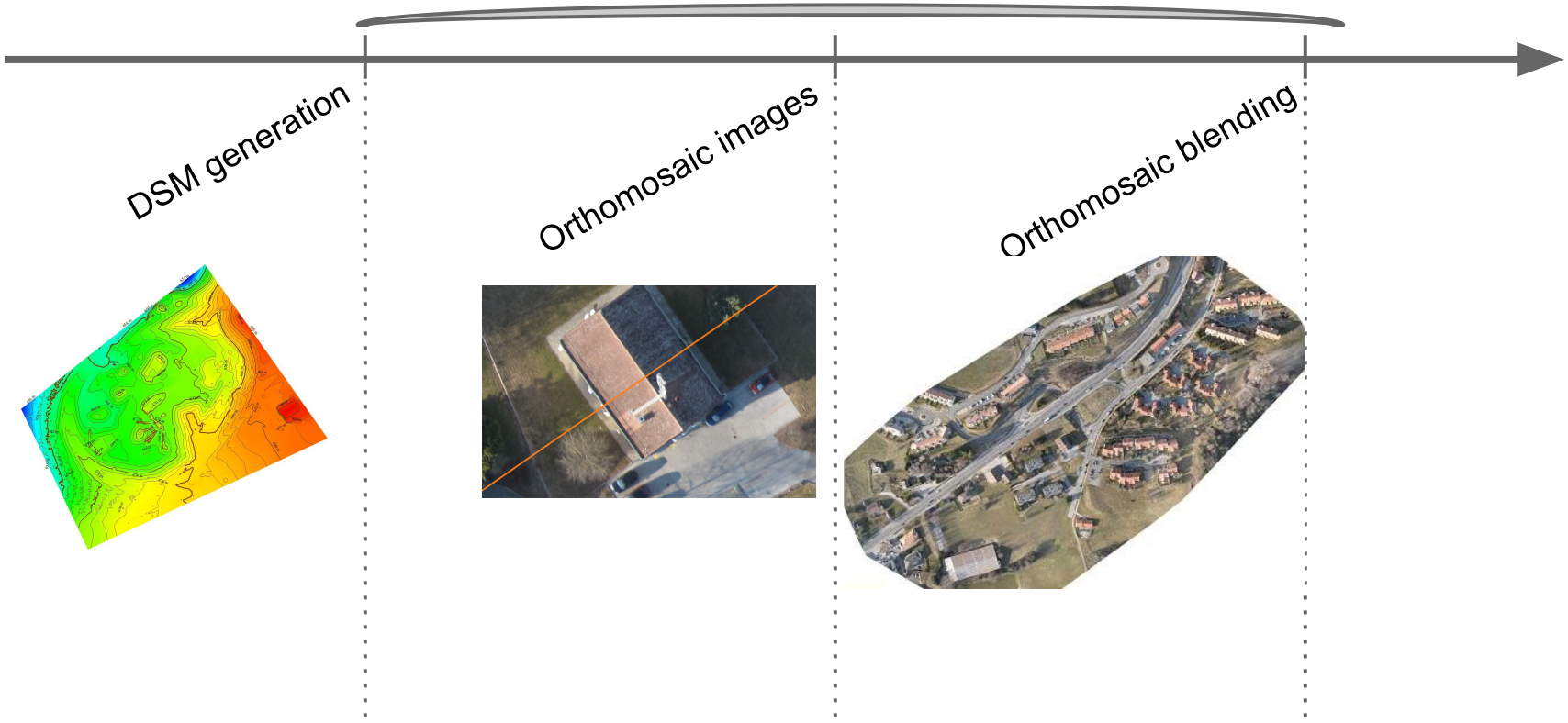
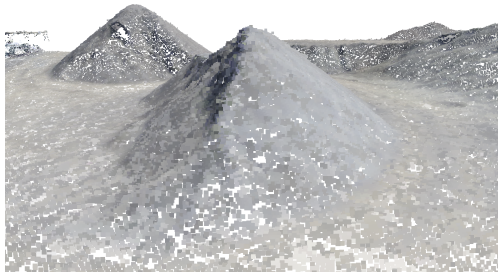
DSM and Orthomosaic

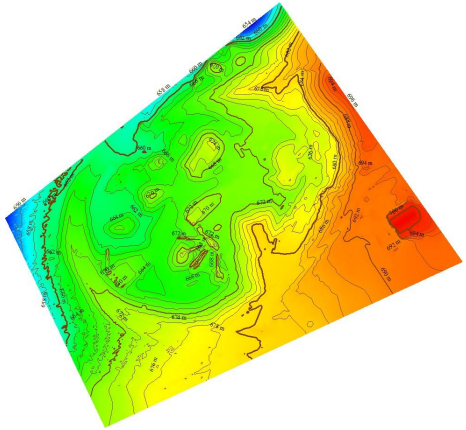
Step 3: DSM and orthomosaic

Point cloud
=> DSM and orthomosaic



DSM generation



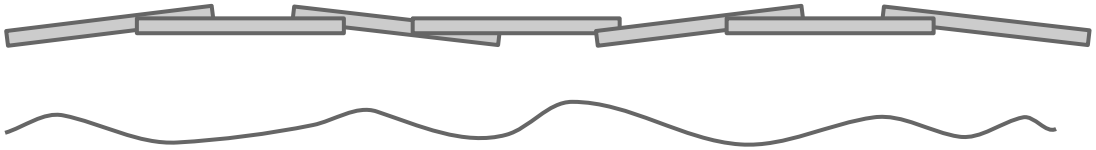


Point cloud => Regular grid of elevation (2.5D)

Interpolation where no points => no holes

DSM accuracy

Interpolation at place with no visual information



Global Accuracy

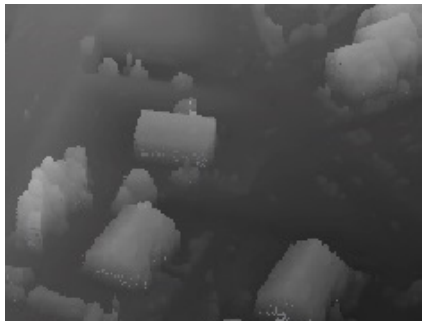
Calibration+Georeference+Point Cloud+Interpolation

Photo Stitching VS Orthorectification

- Glue images together

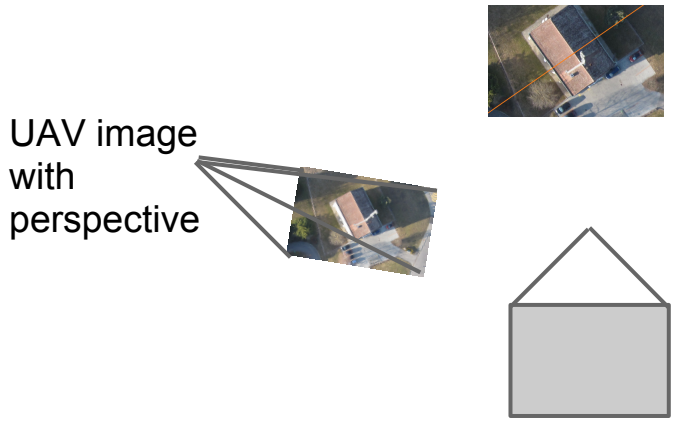
- Works only if terrain perfectly flat
- Error accumulation, only small dataset
- No good georeference support without GCP
- Most distances not preserved
- Requires low number of matches/keypoints (**<100**)

- Undistort perspective using the 3D model and blend images



- Handles any terrain type
- Handles large dataset
- Supports Georeference perfectly
- Preserves distances and becomes measurable
- Requires high number of matches/keypoints (**>1000**) to generate the 3D model

Orthorectification

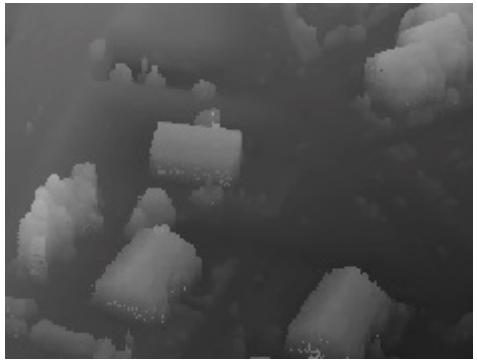


Orthorectify image
1) calibrate camera
2) project image on 3D model
3) generate ortho image by looking from above

UAV image with perspective

- Facade
- Roof not correct size

Computed 3D model



Undistorted orthoimage

- Same as satellite
- Roof correct size

Orthorectification artefacts

3D model not always perfect

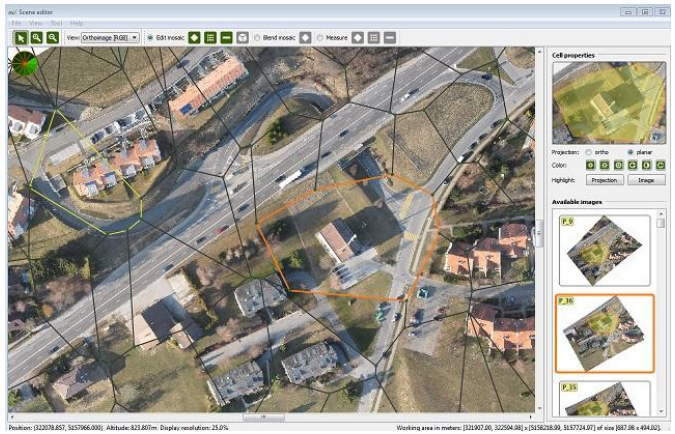
- Edges of buildings
- Small details
  - trees (branches smaller than pixels)
  - lamppost, fences

Orthorectification depends on surface model => artifacts at 3D model errors

Original image tilted: area not visible producing artefacts

3D model not as precise as texture, leading to "wobbly" edges

Blending and Editing



Default: automated blending

Scene editor:

- choose image
- correct brightness
- selective use of orthorectification to generate visually pleasing mosaics

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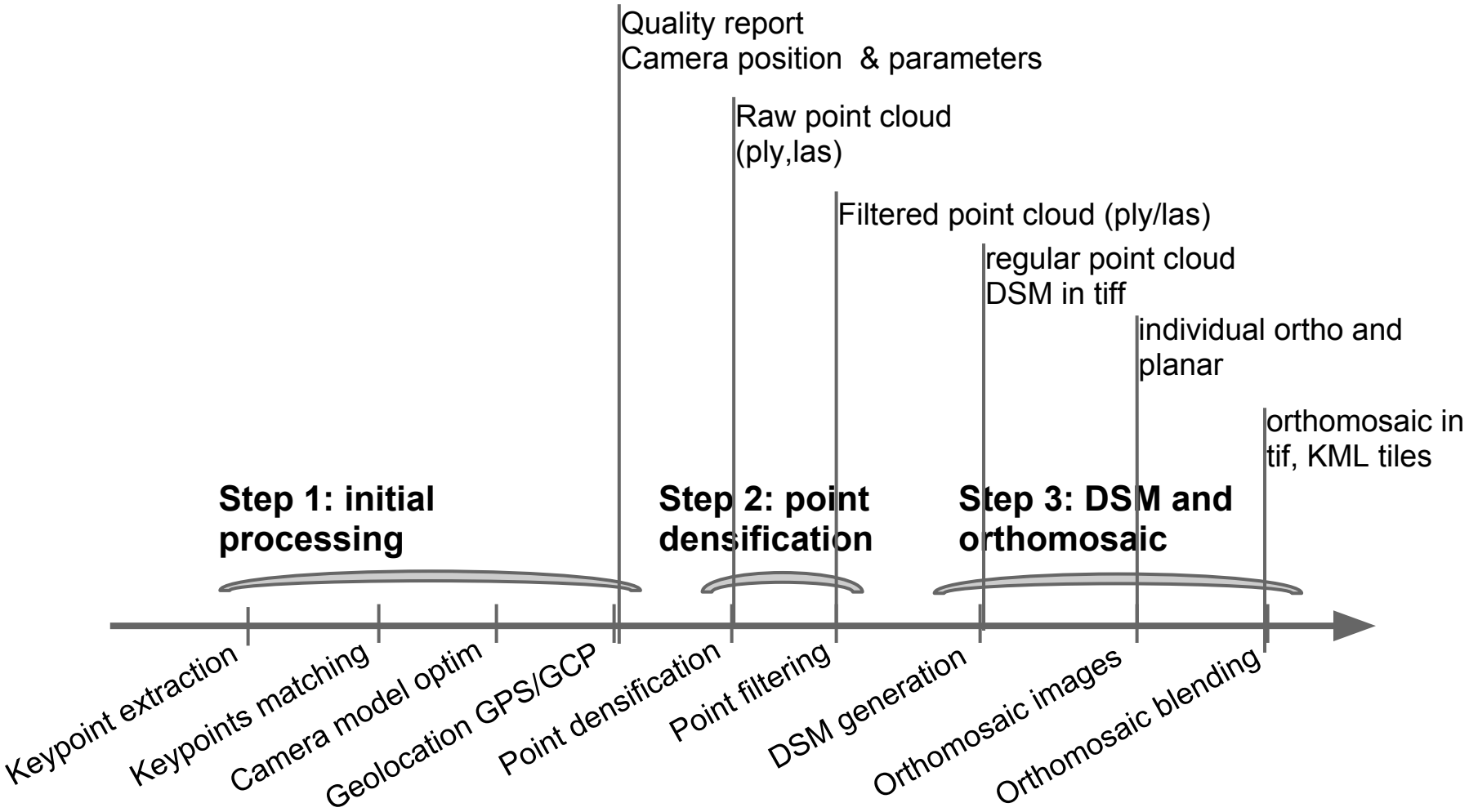
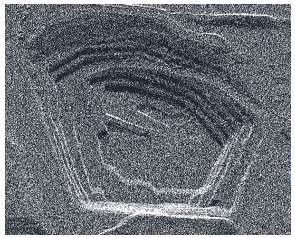
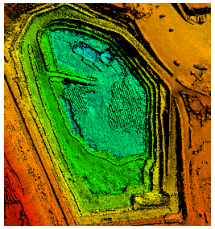
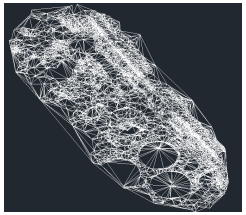
Generated files



Generated files

Pix4uav outputs	Format	Possible use	Examples of compatible software
Raster orthomosaic	geoTIFF (.tiff) KML tiles (.png/.kml)	Area overview Digitize buildings Annotate areas Overlay in GIS package Analyze spectral bands	ArcGIS Global Mapper QuantumGIS AutoCAD Google Earth
Undistorted images	TIFF (.tiff)	Stereo Viewing	ImageMaster
Individual ortho/planar	geoTIFF (.tiff)	Seamline editing	OrthoVista
3D point cloud	.las, .ply, .ascii	Visualization Surface Editing DSM generation DTM generation	ArcGIS Global Mapper AutoCAD Quick Terrain Reader 3D Reshaper Trimble RealWorks Viewer
Raster digital surface model (DSM)	geoTIFF (.tiff)	Analyze surface Measure volumes Generate contour lines Draw breaklines	ArcGIS Global Mapper QuantumGIS Quick Terrain Reader
3D mesh with texture	Wavefront (.obj)	Render in animation package Visualize small projects	AutoCAD Bentley Pointools View CC Viewer 3D Reshaper

Use of generated files

	3D point cloud	Raster DSM	3D Mesh
			
Editing	**best (VRMesh)**	possible	possible
Analyzing	mainly transform to raster DSM	**best (ArcGIS/Global Mapper)**	small projects only
Visualization	**good (Quick Terrain Reader)**	**good (ArcGIS/Global Mapper)**	small projects only

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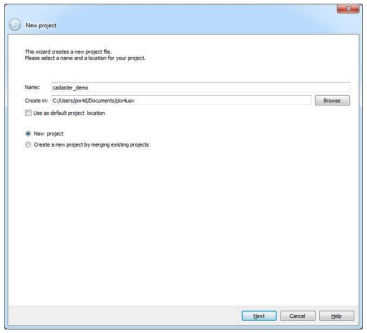
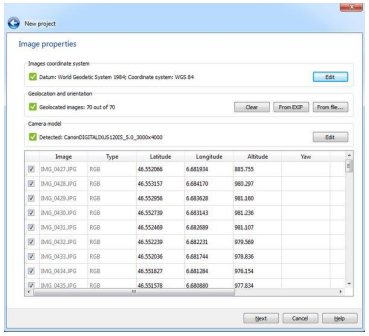
Software Demo: create project

3 Step wizard



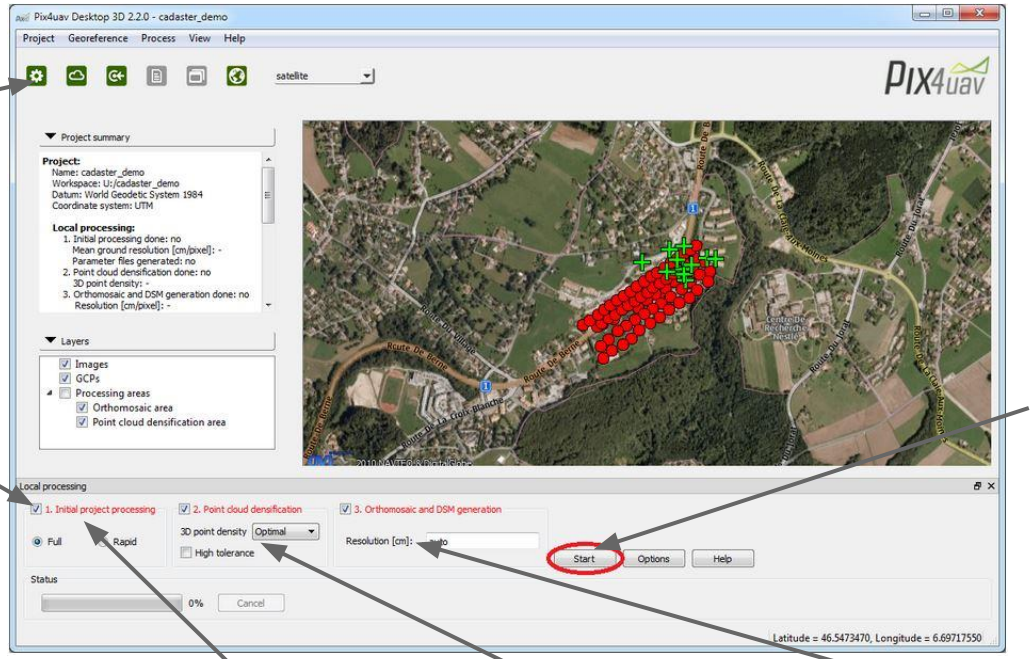
1&2)
- create project, import images
- is also used to "merge" overlapping project. Split and merge when computer resources not sufficient, or when calibration issues between areas of project.



3)
geotags and camera model selection
- automatic geotag, or using text file
- automatic camera model selection, or using database
- at least three valid geotag required

Software Demo: main interface

1) Processing button

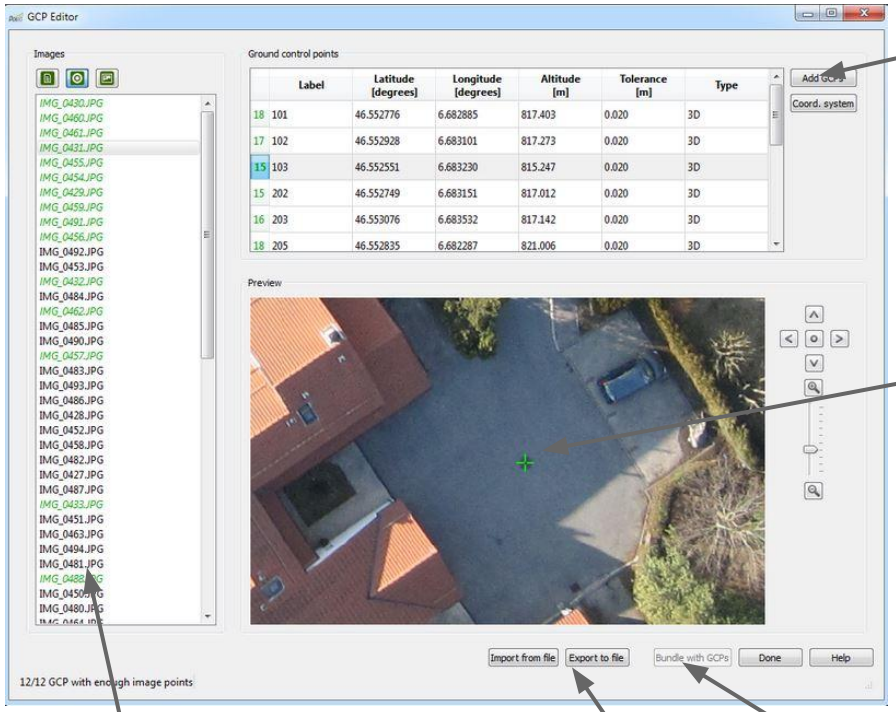


2) Start button

Steps in red if not yet processed. Checkbox allows run of individual step.

	Initial Processing:	Point densification:	Orthomosaic/DSM:
	Option: rapid,full	Option: density	Option: resolution
127 images 12 MP Canon Ixus quadcore laptop	**rapid**: 3 min, low accuracy **full**: 14 minutes	**optimal**: 28 min Choose *high tolerance* if forest	**auto** will select average computed GSD: 15 min Can be replaced by any other number

Software Demo: GCP editor



1) Add GCP/control/verification using file OR right click

3) Measure GCP in at least 2 images per GCP, 5 recommended

2) List of images
use top icons to sort closest images
use right click to remove measurements

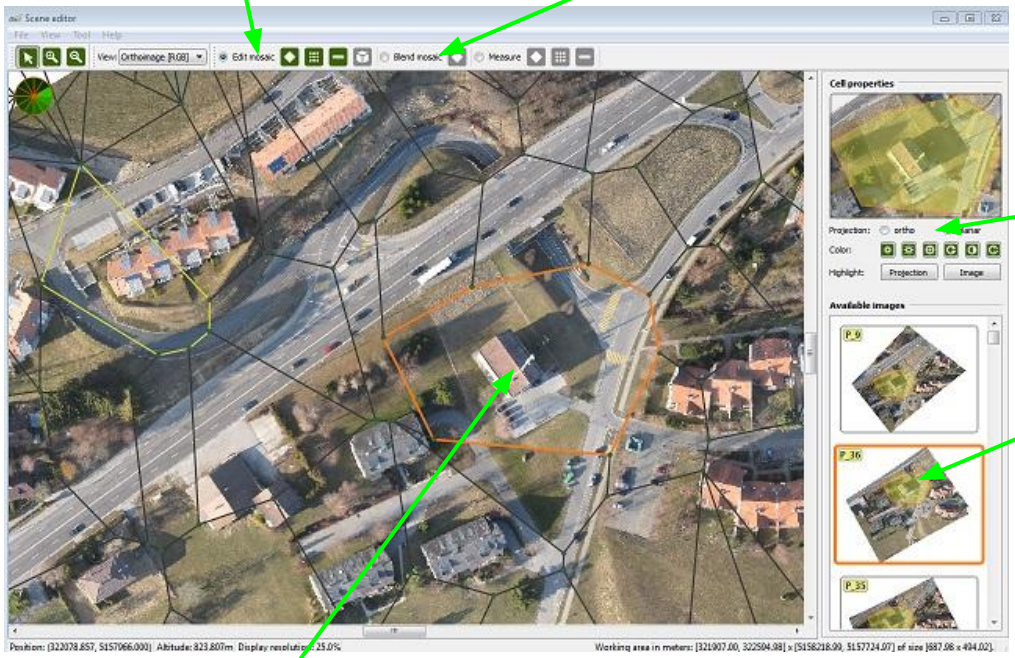
4) Import/export clicked points without coordinates

5) If initial processing is already done, bundle with GCP allows for faster re-processing

Software Demo: Scene Editor

4) Change/Add cells using polygon/line/points tools

5) Blend mosaic



2) Select ortho/planar to improve visual aspect

3) Choose most appropriate image in the list (use keyboard up/down arrow). Good to remove blurry images/ moving cars

1) Select a cell by clicking

Thank you