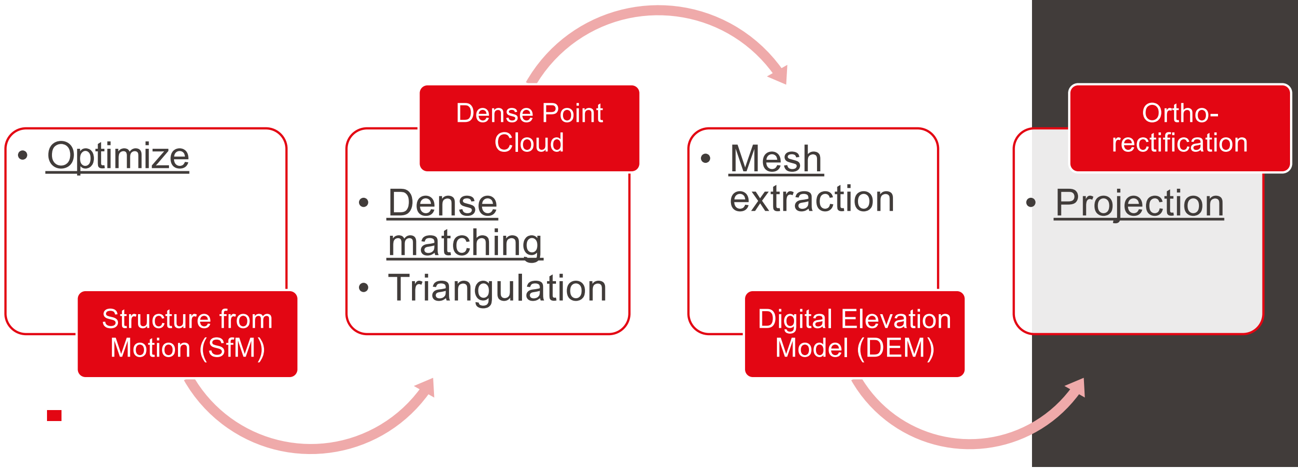
Optimization

Dense matching / 3D point cloud

3D meshes and elevation models

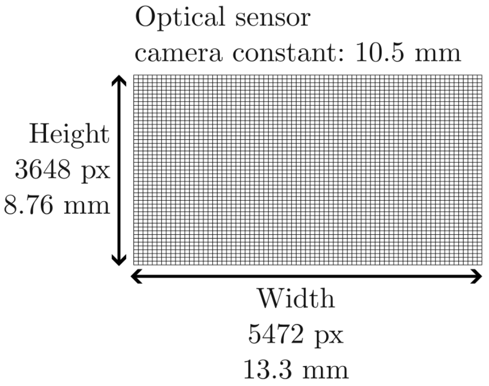
Orthorectification

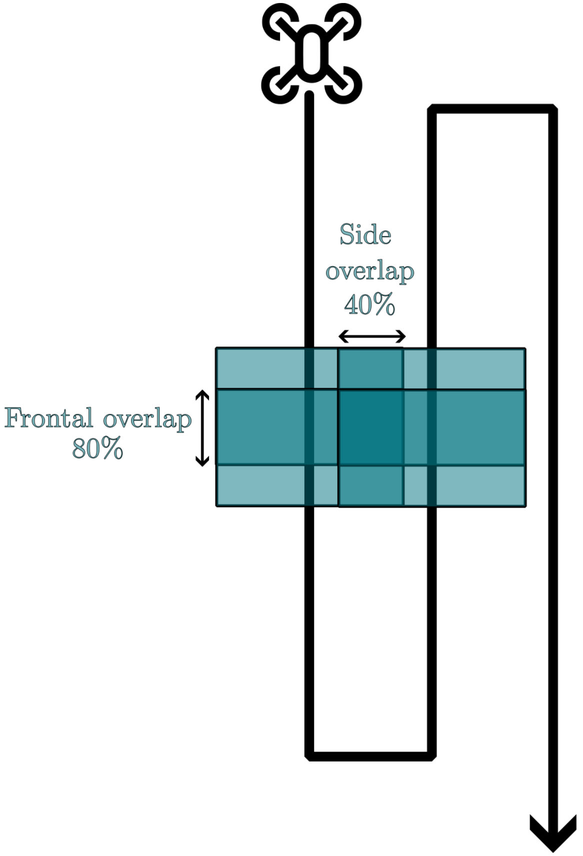
Appendix I. planning exercise 4 exam!
II. optimization factors
III. epipolar image generation
IV. image vs. lidar point-cloud

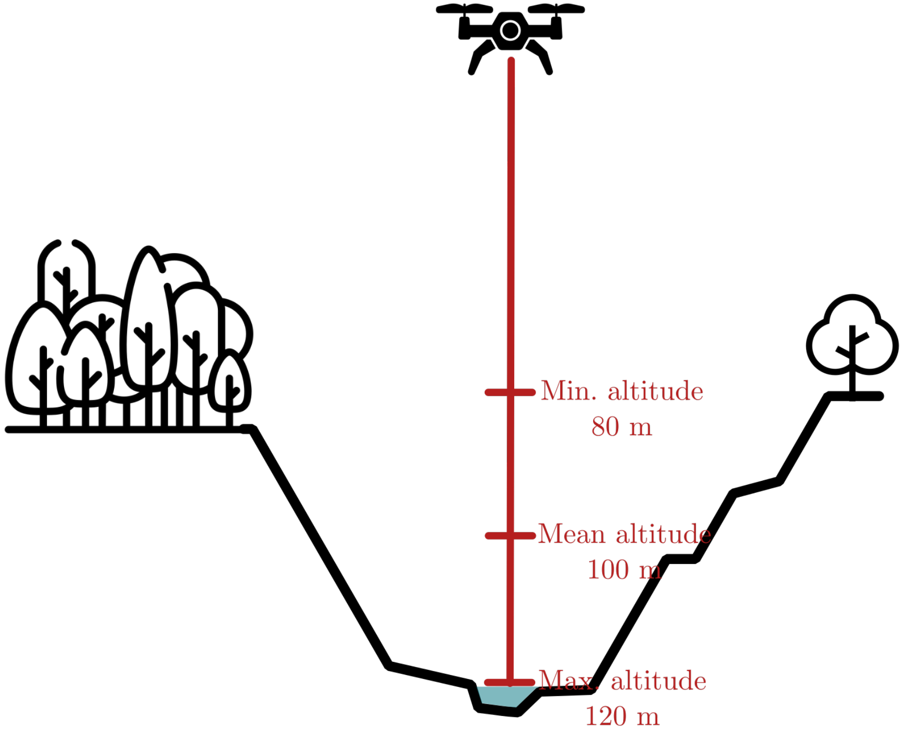


Exercise: mission planning

Drone corridor survey of a natural groove

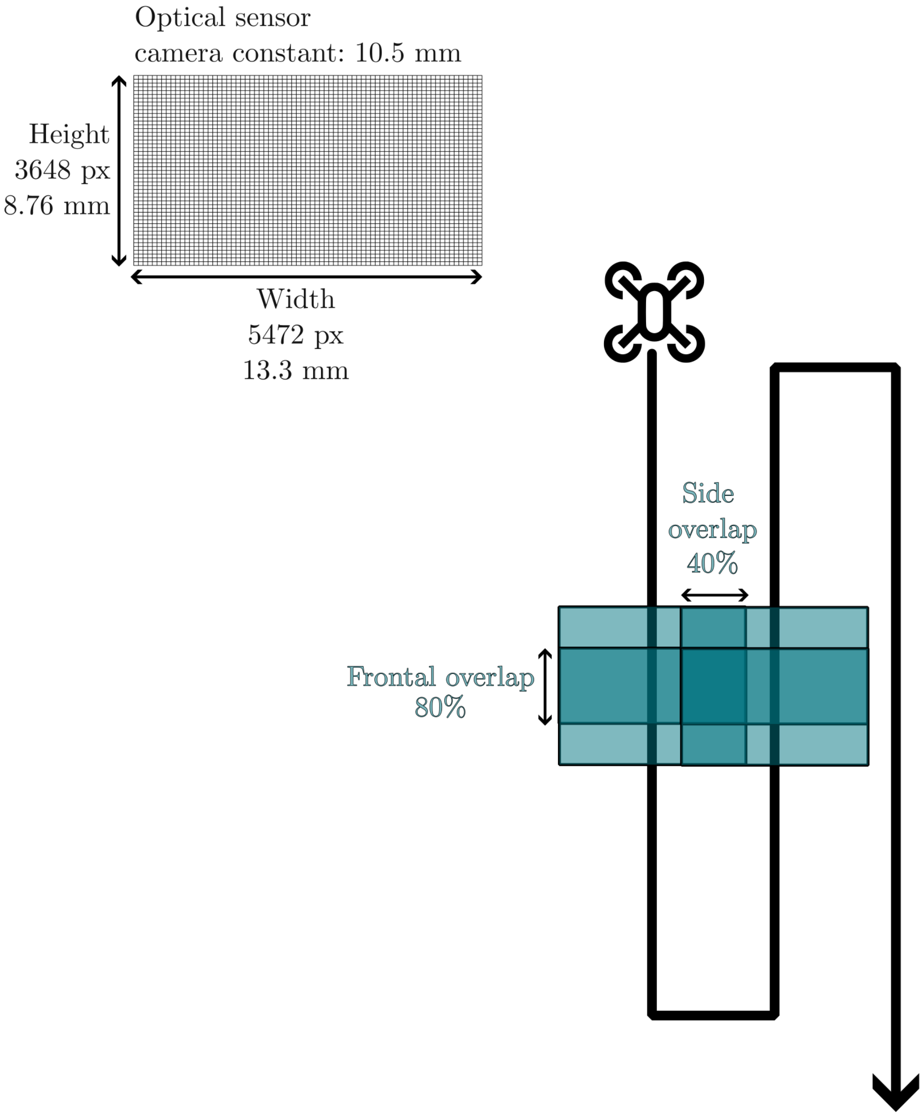






Exercise: mission planning

Drone corridor survey of a natural groove



I. **Estimate**
   i. **sensor *FOV* (cross-track)**

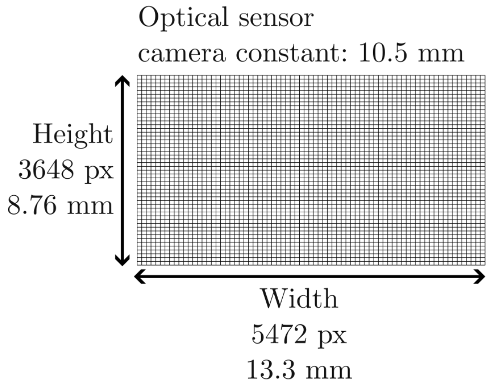
   ii. **the mean *image scale***

   iii. **the mean *GSD***

II. **Estimate GSD variability over terrain**

Exercise: mission planning

Drone corridor survey of a natural groove



Optical sensor
camera constant: 10.5 mm

Height
3648 px
8.76 mm

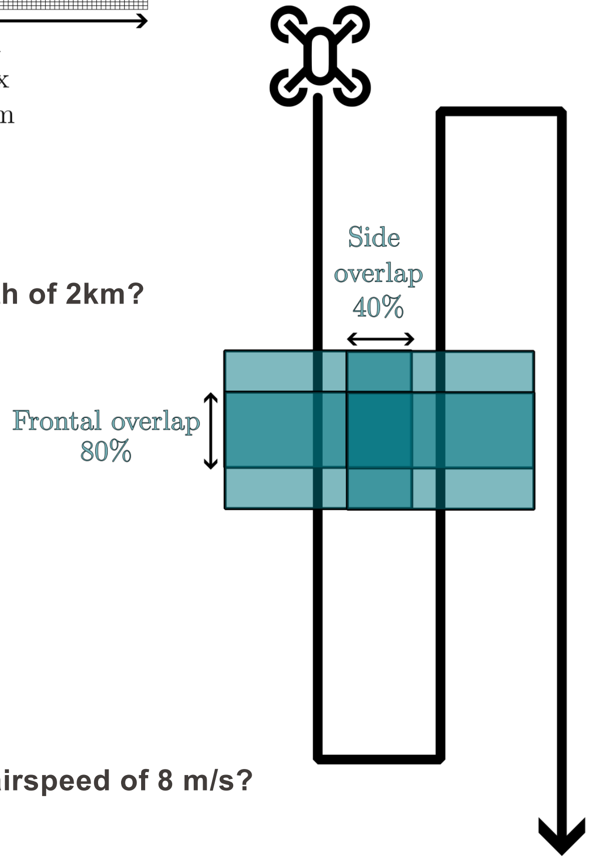
Width
5472 px
13.3 mm

III. What is the distance between two flight lines ?

IV. What is no. of images for a max. frame-per-sec (FPS) of 0.5 Hz and total path length of 2km?

V. What is max. ground speed of the drone for the given FPS and overlap?

VI. What do you suggest to do if you would like to do a fixed-wing drone with a min. airspeed of 8 m/s?

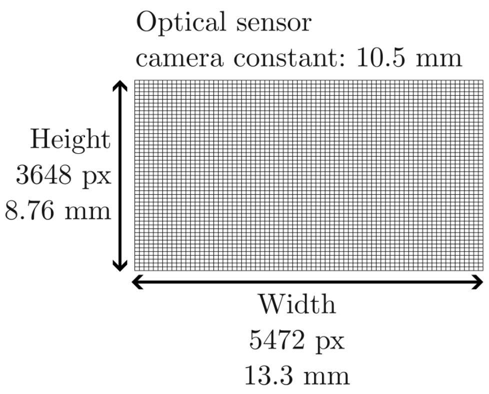


Side overlap 40%

Frontal overlap 80%

Exercise: mission planning

Drone corridor survey of a natural groove



Optical sensor
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Height
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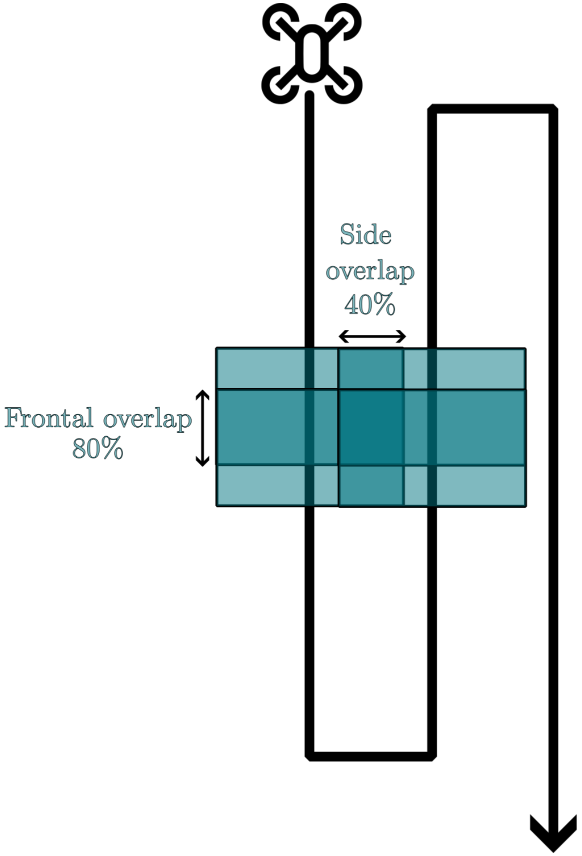
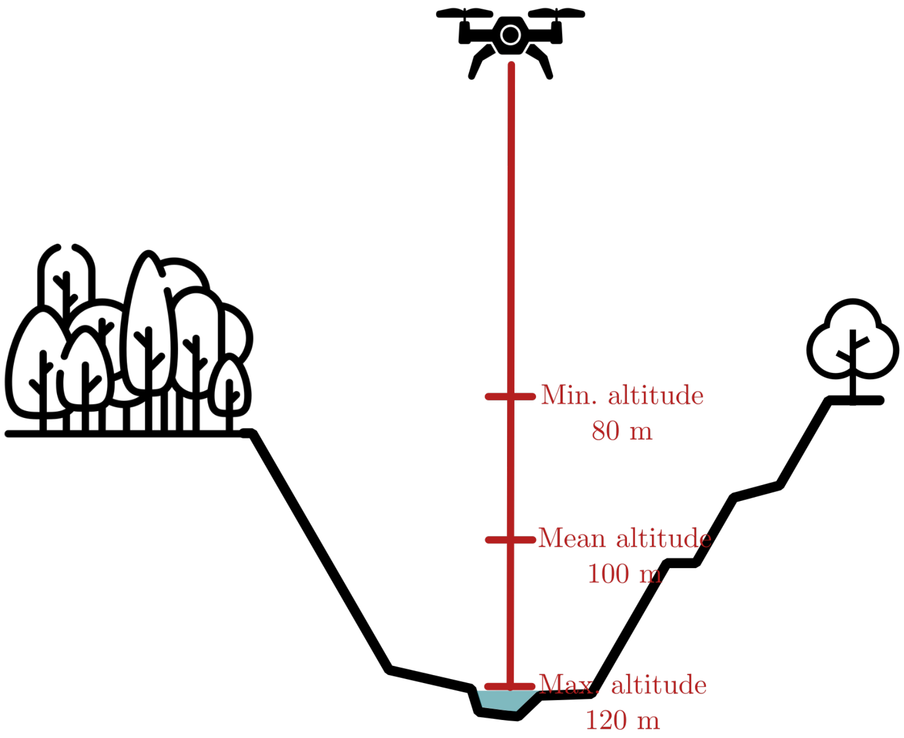


Side
overlap
40%

Frontal overlap
80%



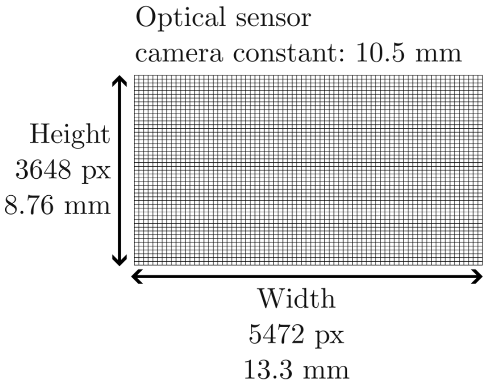
Min. altitude
80 m

Mean altitude
100 m

Max. altitude
120 m

Exercise: mission planning

Drone corridor survey of a natural groove



I. **Estimate**
  i. **Sensor field of view *FOV* (cross-track)**

$$FOV = \frac{sensor_{width}}{c} = \frac{13.3}{10.5} = 1.27\,rad \approx 80^\circ$$

  ii. **Mean *image scale***

$$scale = \frac{AGL_{mean}}{c} = \frac{100}{10.5e-3} = 9.52 \cdot 10^3 \approx 10^4 = 1\ :\ 10\,000$$

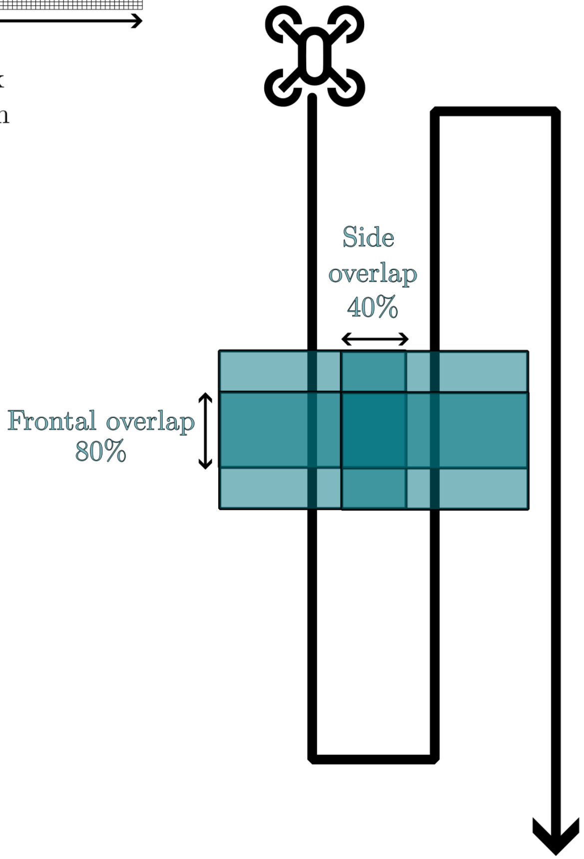
  iii. **Mean *GSD***

$$GSD_{mean} = size_{pixel} \cdot scale = \frac{13.3e-3}{5472} \cdot 9.52e3 \approx 2.4 \cdot 10^{-6} \cdot 10^4 = 0.024\,\mathrm{m}$$

II. **Estimate GSD variability over terrain**

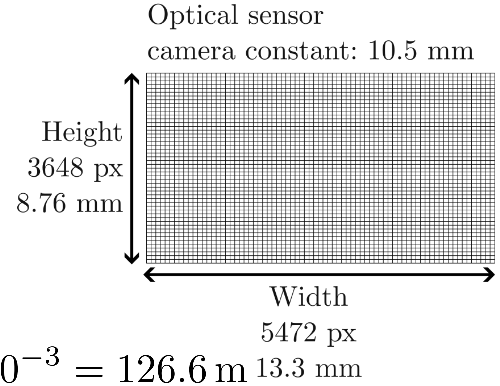
$$\Delta_h = \pm 20\,\mathrm{m}$$

$$\Delta_{GSD} = \frac{\Delta_h}{scale} = \pm 0.002\,\mathrm{m} \Leftrightarrow \sim 10\%\ \ \mathrm{GSD}$$



Exercise: mission planning

Drone corridor survey of a natural groove



III. **What is the distance between two flight lines ?**

$$side_{print} = scale \cdot sensor_{width} = 9.52\,10^3 \cdot 13.3\,10^{-3} = 126.6\,\mathrm{m}$$

$$d_{side} = (1 - overlap_{side}) \cdot side_{print} = 0.6 \cdot 125.9 = 75.5\,\mathrm{m}$$

IV. **What is no. of images for a max. frame-per-sec (FPS) of 0.5 Hz and total path length of 2km?**

$$front_{print} = scale \cdot sensor_{height} = 9.52\,10^3 \cdot 8.76\,10^{-3} \approx 84\,\mathrm{m}$$

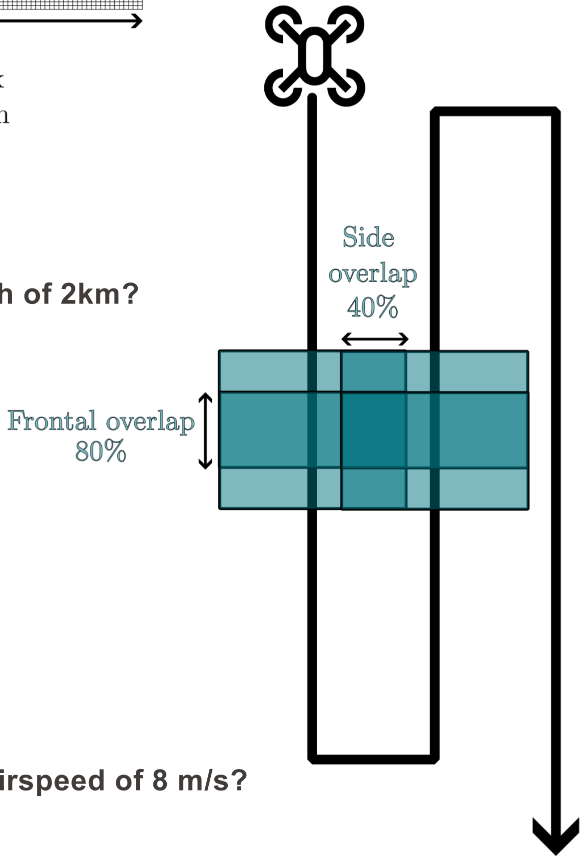
$$d_{front} = (1 - overlap_{front}) \cdot front_{print} = 0.2 \cdot 83.4.9 \approx 17\,\mathrm{m}$$

$$N_{img} = \frac{L}{d_{front}} = 2000/16.7 = 120$$

V. **What is max. ground speed of the drone for the given FPS and overlap?**

$$v = d_{front} \cdot framerate \approx 8.4\,\mathrm{m/s}$$

VI. **What do you suggest to do if you would like to do a fixed-wing drone with a min. airspeed of 8 m/s?**



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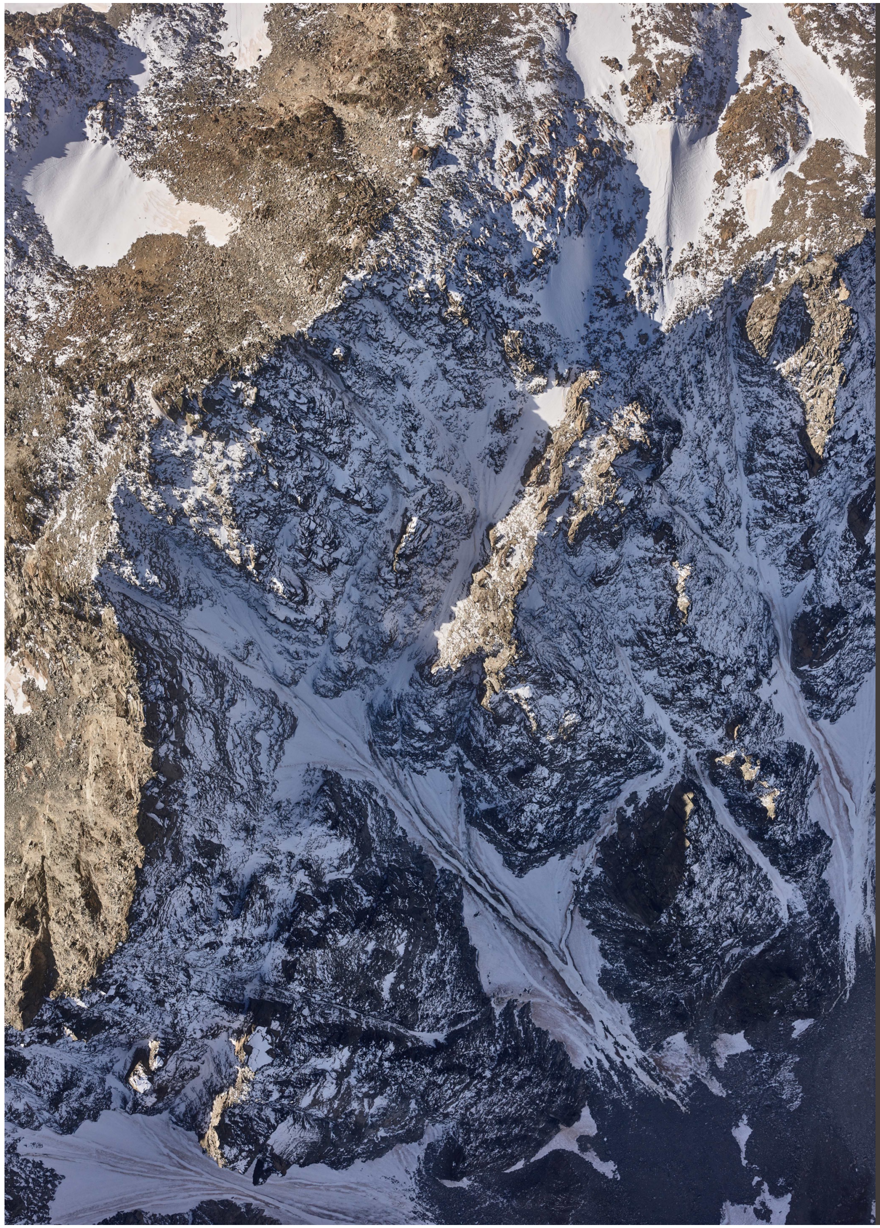
Appendix II. optimization factors

Optimization – influencing factors

	Factor	**Constraint**
Sensor-given	Image resolution (point spread function)	Lens / filter / sensor assembly quality
	Sensor size (given) & c: focal-length (?)	Pixel size, # pixels, field of view
	Dynamic range, exposure-time, min. dt	# bits / shutter speed / write-time
Specifications	Ground resolution (GSD)	Pixel size (um), [c / flying height (AGL) = scale]!!!
	Blur % per pixel	Exposure-time vs. aperture vs. platform speed
Situation	Terrain type	Height variations & texture (matching quality!)
External	Max / min flying height	Legal, security aspects, authorization
Geometry	Overlap, image convergence, cross-strip	Terrain variations, stabilization, write-time, speed
	Pose priors	Nav. sensors – presence & quality + dynamics
	Ground control	# and distribution vs terrain accessibility & cost

Merits of additional observations

Type	Advantage	Constraint
Ground. Control Points (GCP) P_i^m	Camera can operate standalone	High number of points needed - laborious
GCP as Check Points P_i^m	Independent control of camera orientation / calibration	Does not improve directly camera orientation / calibration
Camera position $t_{c,j}^m$	Efficient control with cm-level GPS (RTK/PPK) In block: no need for GCP	Obstruction free environment required (problem on terrestrial vehicles) Block configuration needed
Camera pose $t_{c,j}^m$ $R_m^{c,j}$	The most efficient control with low-noise IMU & cm-level GPS Block/corridors: no need for GCP	More complex system For small low-cost IMU, attitude quality depends on vehicle dynamic & mission duration.



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Appendix III. epipolar image generation

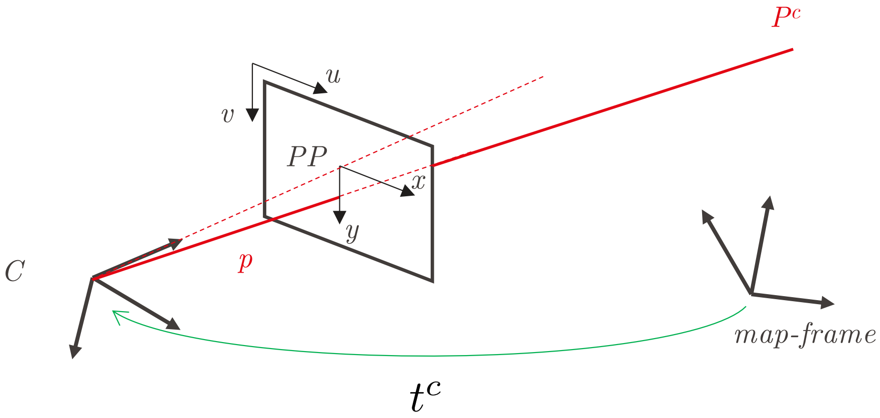
Epipolar image generation 1/5

(stereo rectification)

In Lecture 3 we have defined the perspective projection via the collinearity eq. that transforms points **from map**-frame **to camera**-frame

C - camera

$$\mu \begin{pmatrix} u_L \\ v_L \\ 1 \end{pmatrix} = K \cdot [R|t]^c_m \cdot P^m = K \cdot P^c$$



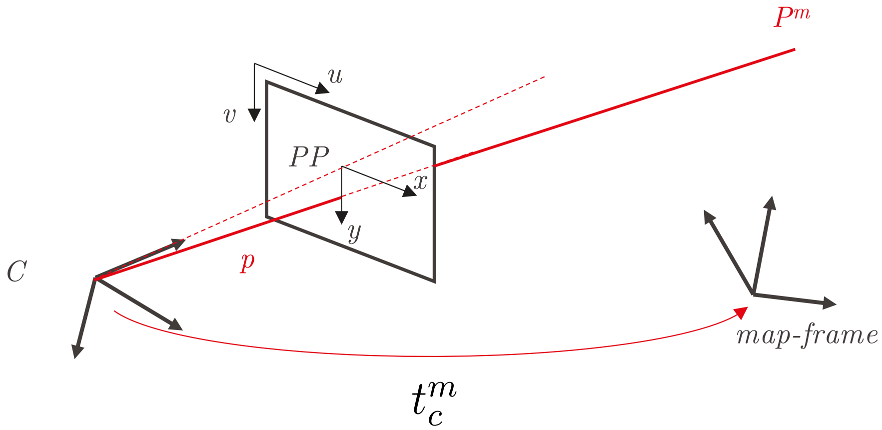
Epipolar image generation 2/5

(stereo rectification)

For stereo-vision it is more common to use an inverse projection with $[R|t]^{-1}$,i.e. transforming points **from camera**-frame **to map-**frame, where t_c^m is camera center directly in map-frame.

C - camera

$$\mu \begin{pmatrix} u_L \\ v_L \\ 1 \end{pmatrix} = K \cdot \left([R|t]_m^c\right)^{-1} \cdot P^c = K \cdot R_m^c \cdot (P^m - t_c^m)$$



Epipolar image generation 3/5

(stereo rectification)

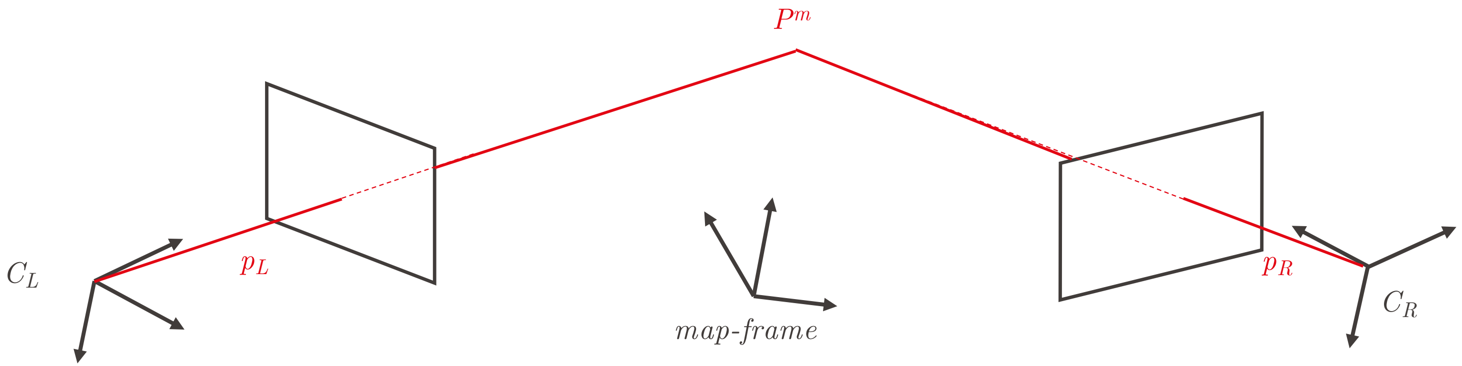
Write the perspective equation for left & right cameras (which may have different K)

Left camera

$$\mu \begin{pmatrix} u_L \\ v_L \\ 1 \end{pmatrix} = K_L (R^c_m)_L \left(P^m - t^m\right)$$

Right camera

$$\mu \begin{pmatrix} u_R \\ v_R \\ 1 \end{pmatrix} = K_R (R^c_m)_R \left(P^m - t^m\right)$$



Fussielo, Trucco Verri, 1999. A compact algorithm for rectification of stereo pairs. Int. conf. on computer vision (ICVV)

Epipolar image generation 4/5

(stereo rectification)

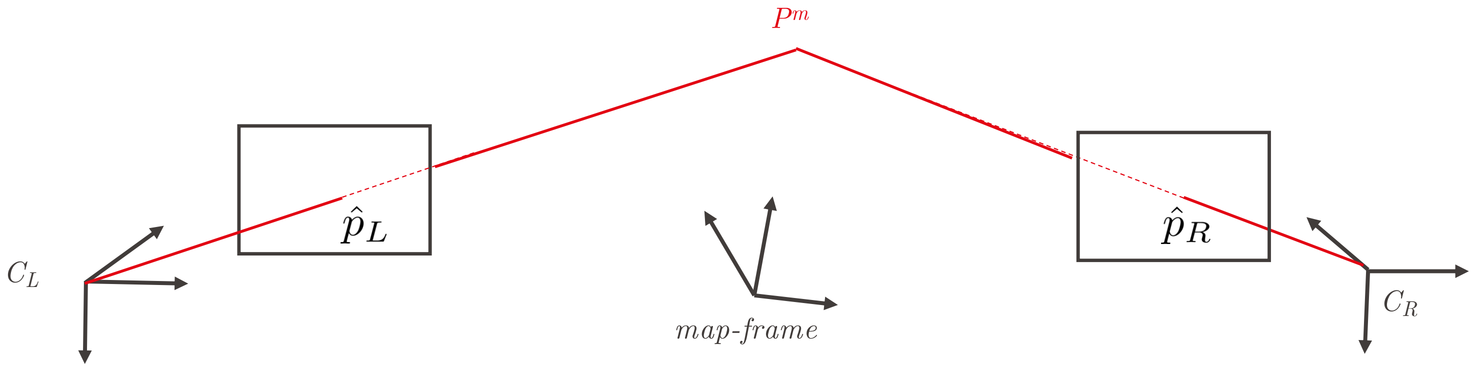
Goal warp left & right images such their image planes are coplanar (have **same** R^*) and have **same** K^*.

Before, left cam: $\mu \begin{pmatrix} u_L \\ v_L \\ 1 \end{pmatrix} = K_L (R^c_m)_L \, (P^m - t^m)$

Before, right cam: $\mu \begin{pmatrix} u_R \\ v_R \\ 1 \end{pmatrix} = K_R (R^c_m)_R \, (P^m - t^m)$

After, left cam: $\rightarrow \hat{\mu} \begin{pmatrix} \hat{u}_L \\ \hat{v}_L \\ 1 \end{pmatrix} = \hat{K} \hat{R}^c_m \, (P^m - t^m)$

After, right cam: $\rightarrow \hat{\mu} \begin{pmatrix} \hat{u}_R \\ \hat{v}_R \\ 1 \end{pmatrix} = \hat{K} \hat{R}^c_m \, (P^m - t^m)$



$^* \; \hat{K}, \; \hat{R}$ (see next slide)

Epipolar image generation 5/5

(stereo rectification)

By solving with respect to $(\mathrm{P^m} - \mathrm{t^m})$for each camera:

Homography matrix can be computed to rectify each camera image

$$\hat{\mu}\begin{pmatrix}\hat{u}_L\\ \hat{v}_L\\ 1\end{pmatrix} = \underbrace{\mu_L \hat{K} \hat{R}^c_m (R^m_c)_L K_L^{-1}} \begin{pmatrix}u_L\\ v_L\\ 1\end{pmatrix}$$

Homography of left camera

$$\hat{\mu}\begin{pmatrix}\hat{u}_R\\ \hat{v}_R\\ 1\end{pmatrix} = \underbrace{\mu_L \hat{K} \hat{R}^c_m (R^m_c)_R K_L^{-1}} \begin{pmatrix}u_R\\ v_R\\ 1\end{pmatrix}$$

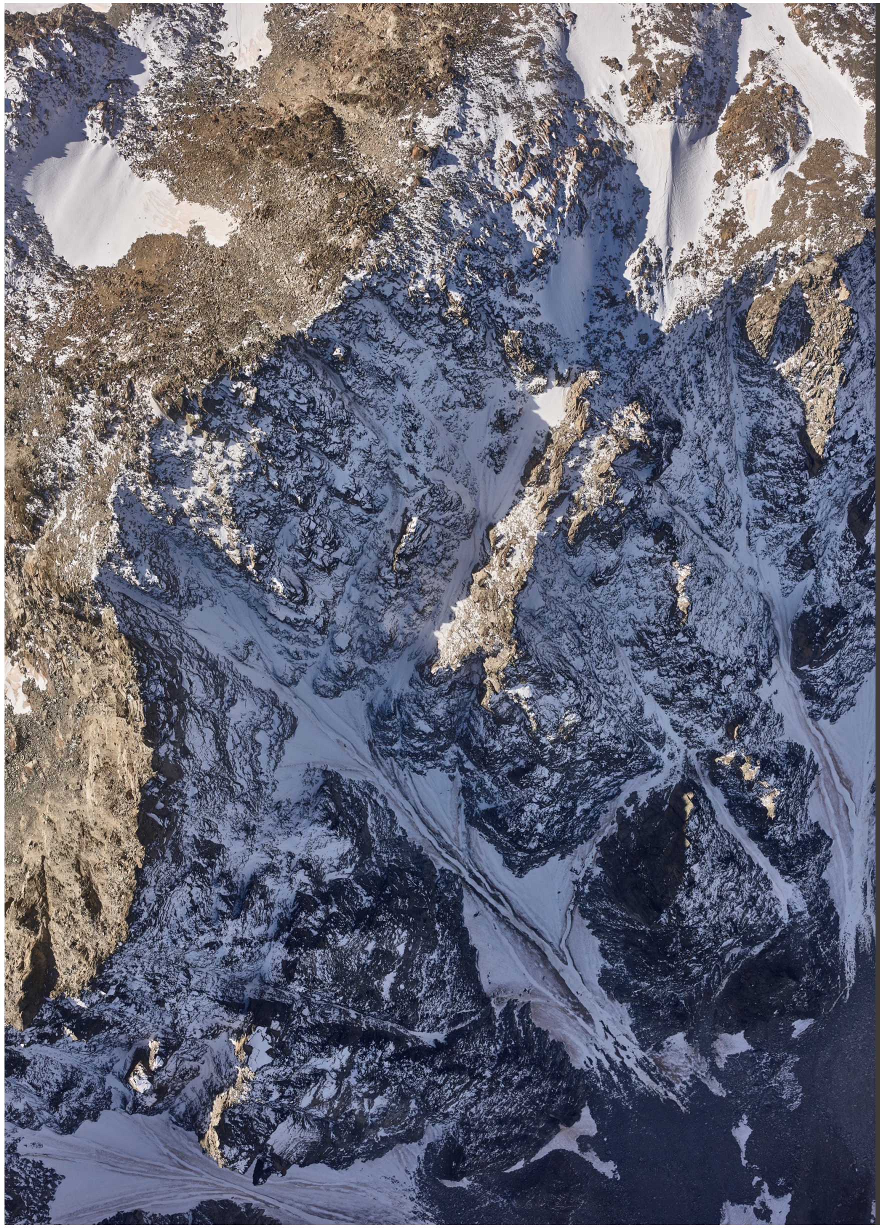
Homography of right camera

- $\hat{R}^c_m = (\hat{r}_1, \hat{r}_2, \hat{r}_3)$ matrix: $\hat{r}_1 = (t_L - t_R)/||t_L - t_R||$
  $\hat{r}_2 = r_{3L} \times \hat{r}_1$
  $\hat{r}_3 = \hat{r}_1 \times \hat{r}_2$

3rd column of R_L

or an alternative: $\hat{r}_2 = 0.5\,(r_{3L} + r_{3R}) \times \hat{r}_1$

- $\hat{K}$ matrix: $\hat{K} = (K_L + K_R)/2$



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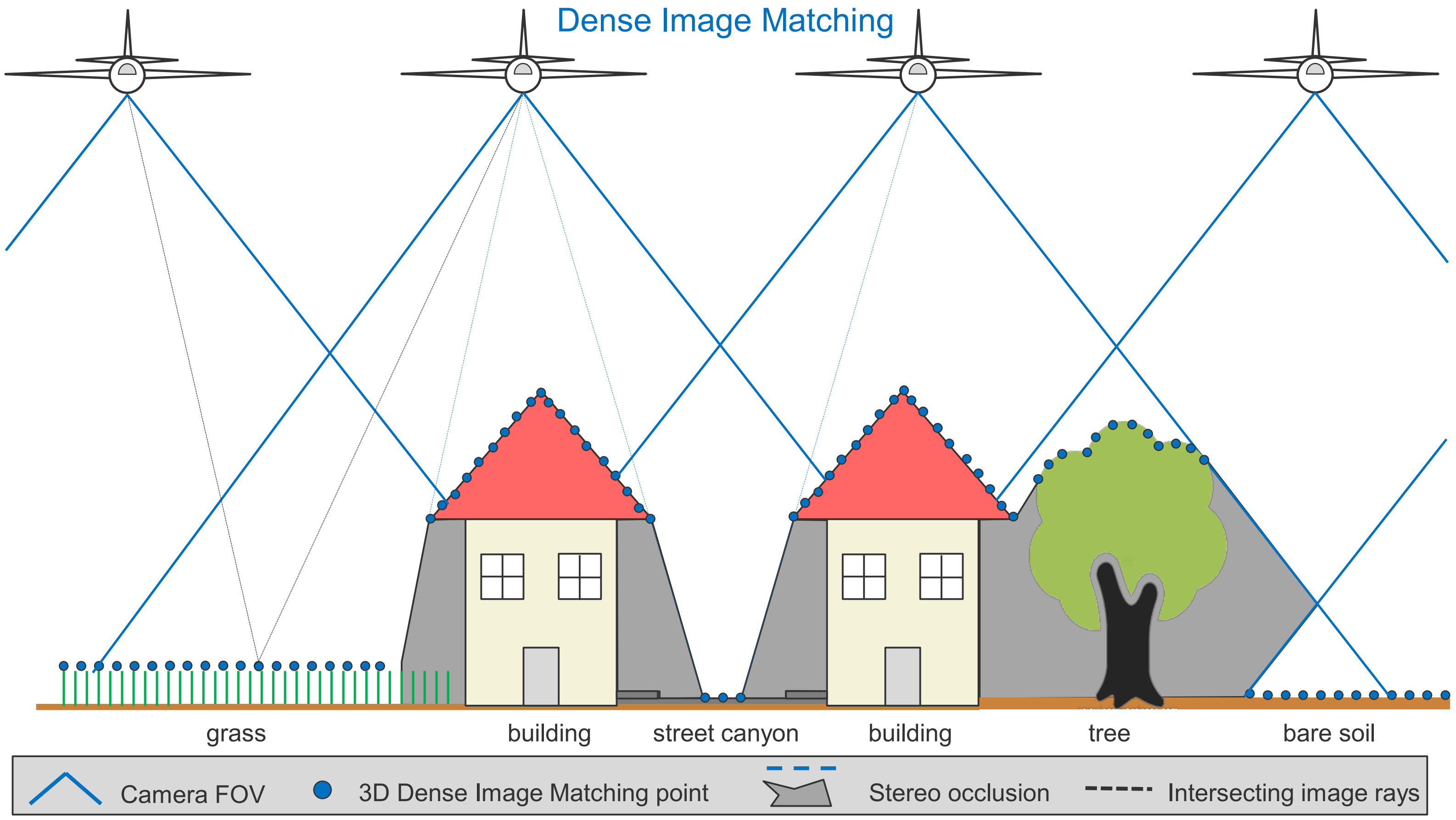
Appendix IV. image vs. lidar point-cloud

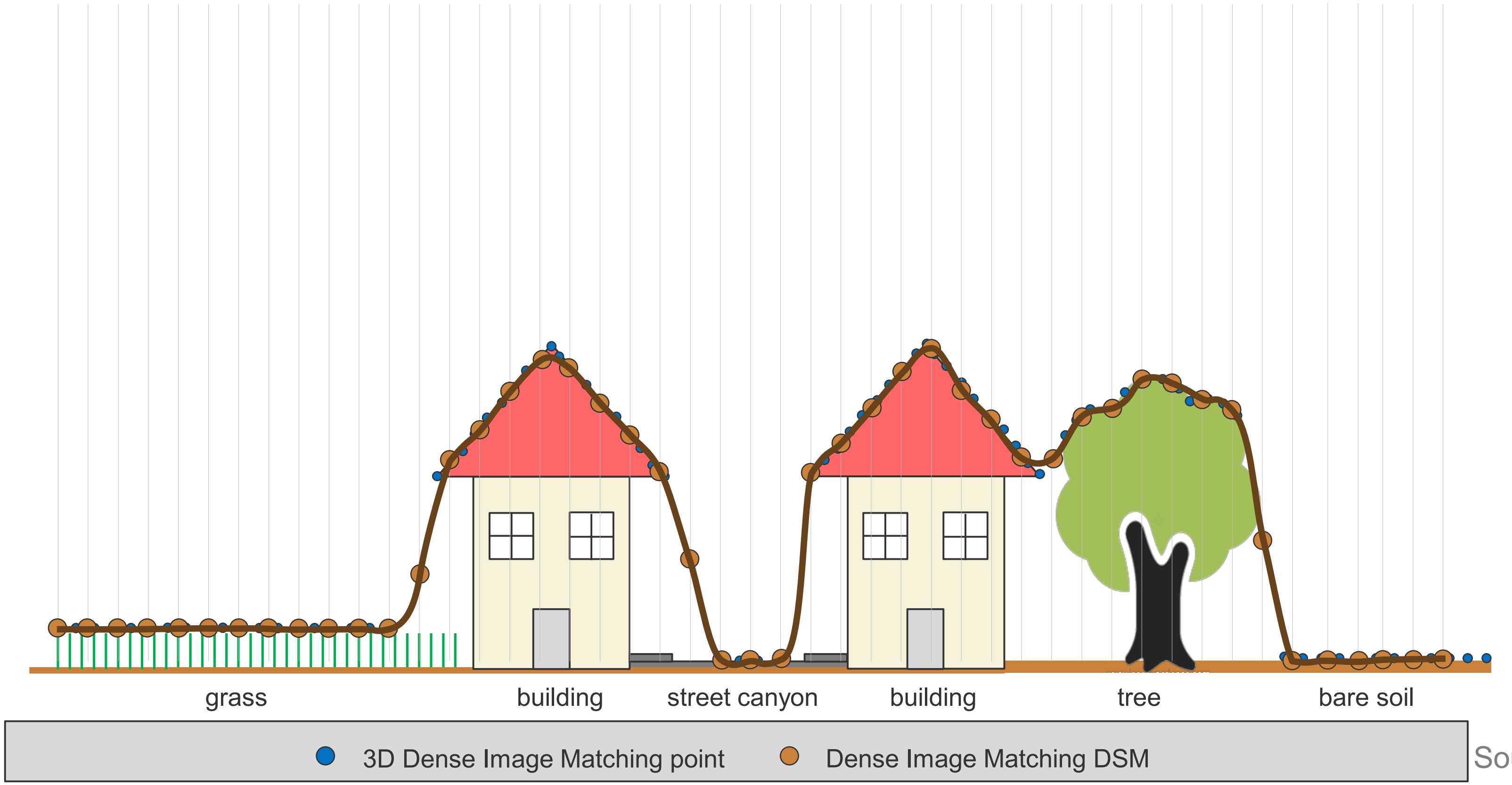
Visibility situation - airborne camera



Source: N. Haala, EuroSDR 2019

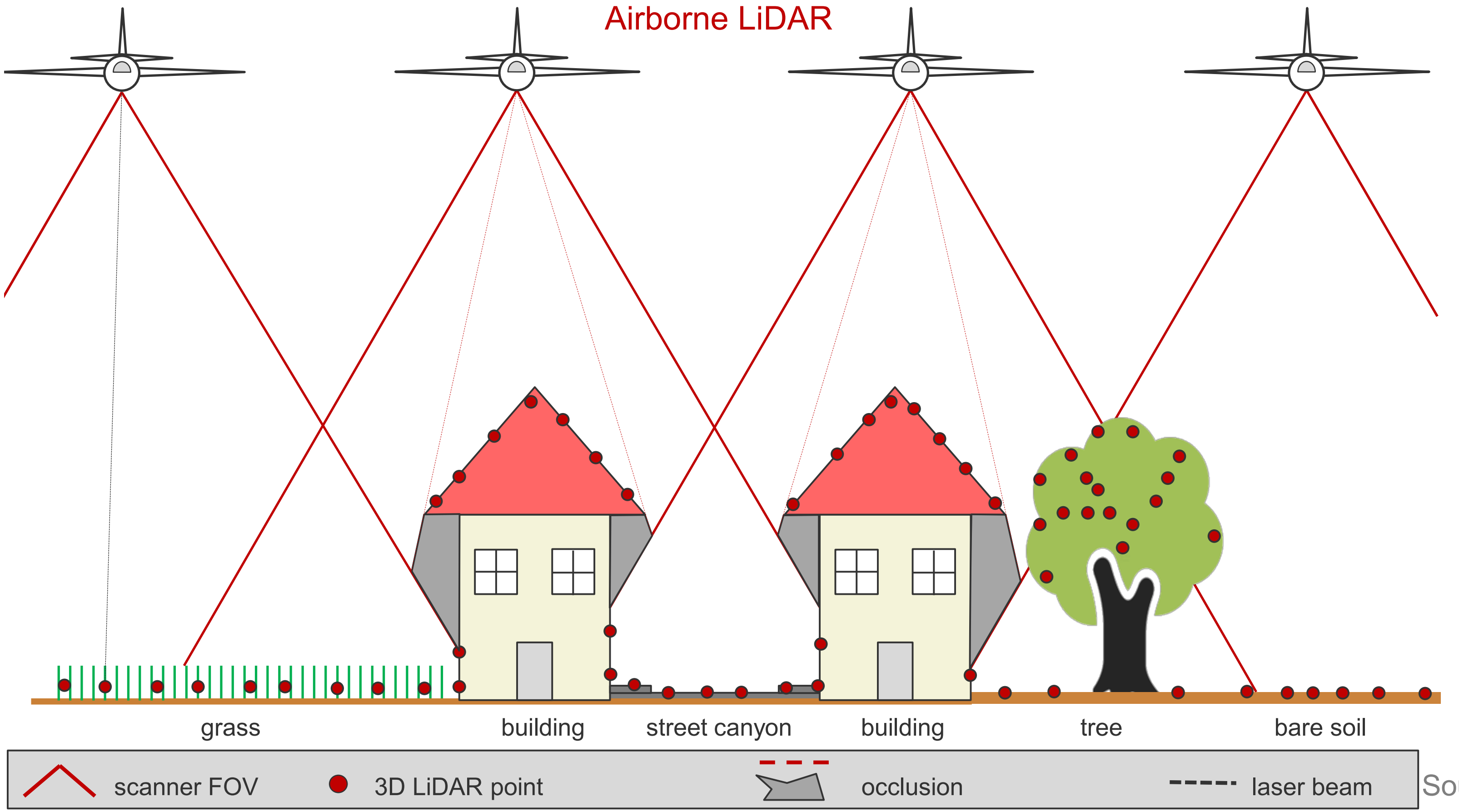
Visibility situation - airborne camera

Dense Image Matching DSM



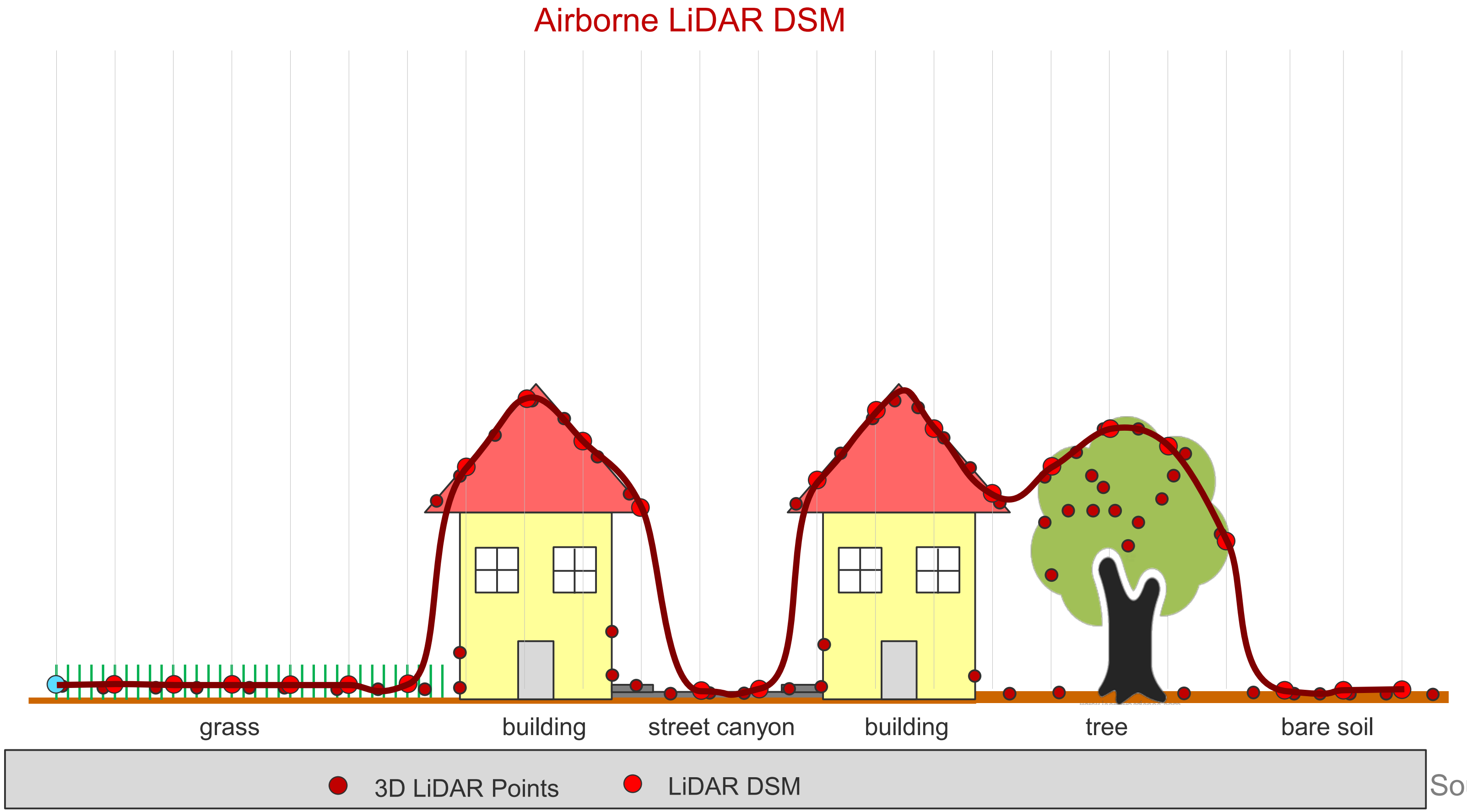
Source: N. Haala, EuroSDR 201

Visibility situation – airborne lasers scanning (ALS)



Source: N. Haala, EuroSDR 201

Visibility situation – airborne lidar scanning (ALS)



Source: N. Haala, EuroSDR 201

3D point cloud creation: dense matching vs lidar

	Airborne lidar (ALS)	**Dense Image Matching**
Data acquisition	multi-sensor system (GNSS + inertial (INS) + scanner + camera)	
Light source	active (laser)	passive (solar radiation)
Measurement principle	time-of-flight	Image ray intersection
Measurement rays per point	1 (polar system)	$\geqslant$ 2 stereo (multi-view)
Target detection	Multiple per pulse (vegetation penetration)	top-most surface (DSM)
Radiometry	normally mono-spectral (though ALS with 3 spectral channels exist)	Multi-spectral (IR)-visible(RGB)-coastal blue)
Typical point spacing	20-50 cm (though 5-10 possible)	5-20 cm
Preconditioning	Diffusion (object reflectance), water!	Radiometric texture
Measurement precision* (1 σ)	1-3 cm	0.5 x GSD
Pose requirements	precise (high-end) INS + GPS/GNSS	Block geometry – possibly no INS

* On well defined, impenetrable surfaces (rocks, roofs, roads, buildings, etc.)