Introduction to Photogrammetry and LIDAR

Mattia Previtali

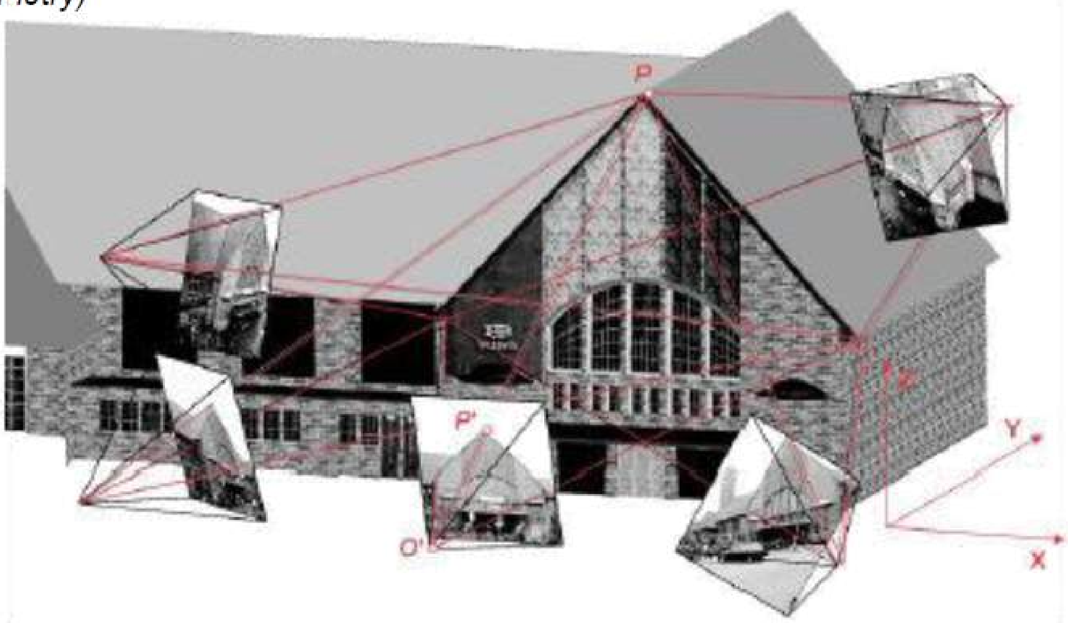
mattia.previtali@polimi.it

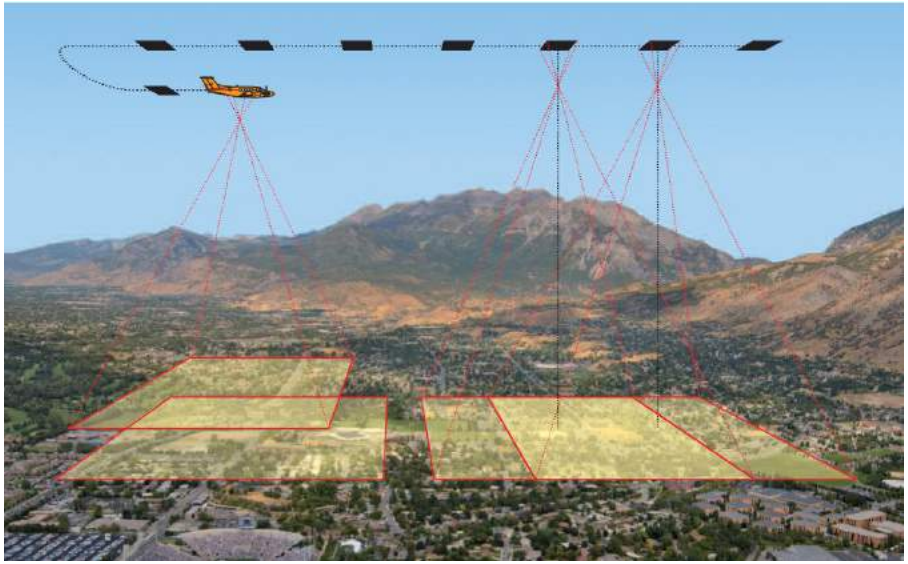
Photogrammetry

Survey technique that allows obtaining metric information (form e position) of three-dimensional objects through interpretation and measurement of photographic images

Definitions:

- *Photogrammetry is the art, science and technology of obtaining reliable information about physical objects and the environment, through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.* (American Society for Photogrammetry and *Remote Sensing - ASPRS)*
- *Photogrammetry allows one to reconstruct the position, orientation, shape and size of objects from pictures: these pictures may originate as photochemical images (conventional photography) or as photoelectrical images (digital photography).* (Karl *Kraus, 2008. Photogrammetry)*

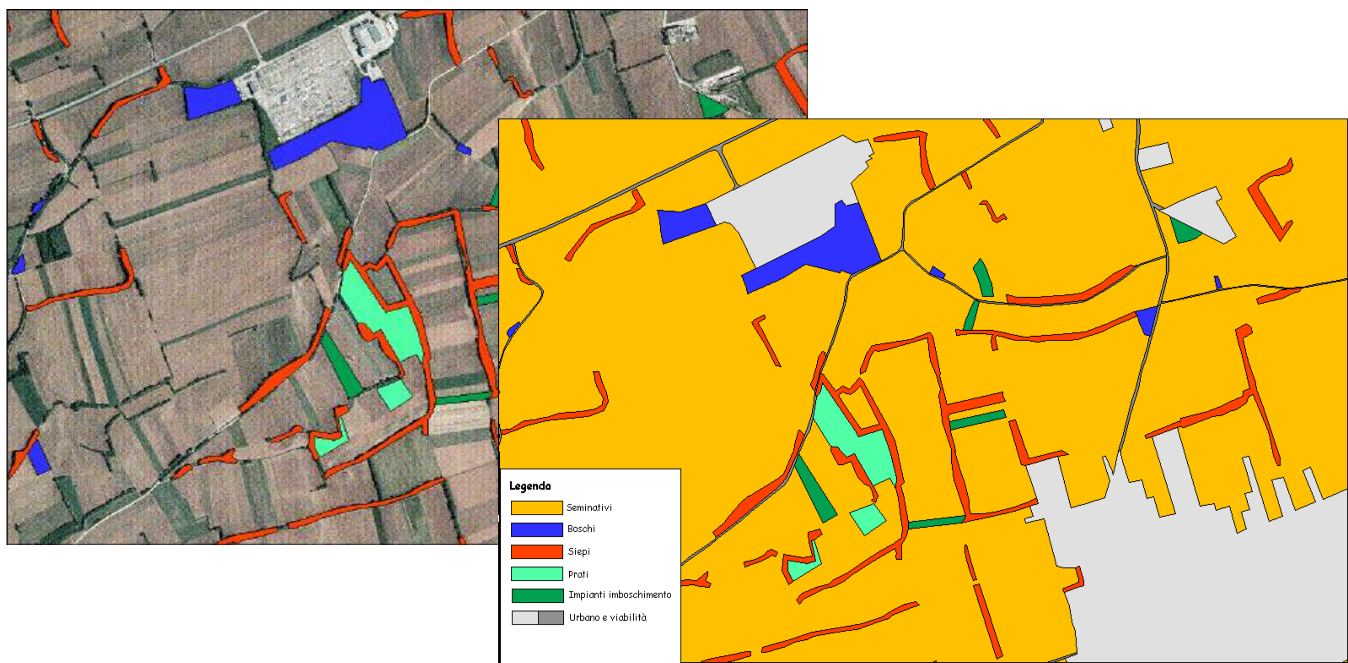




Images

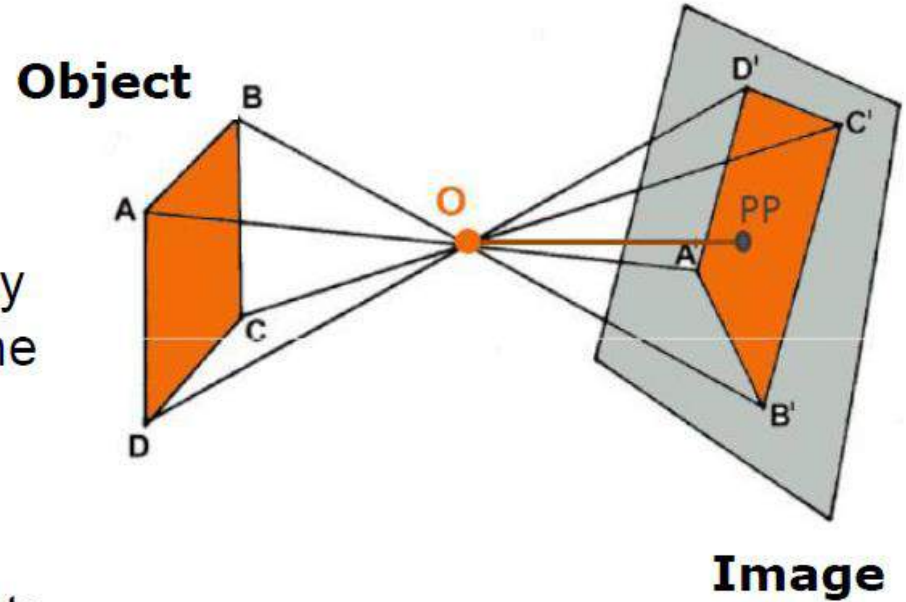
Photogrammetry

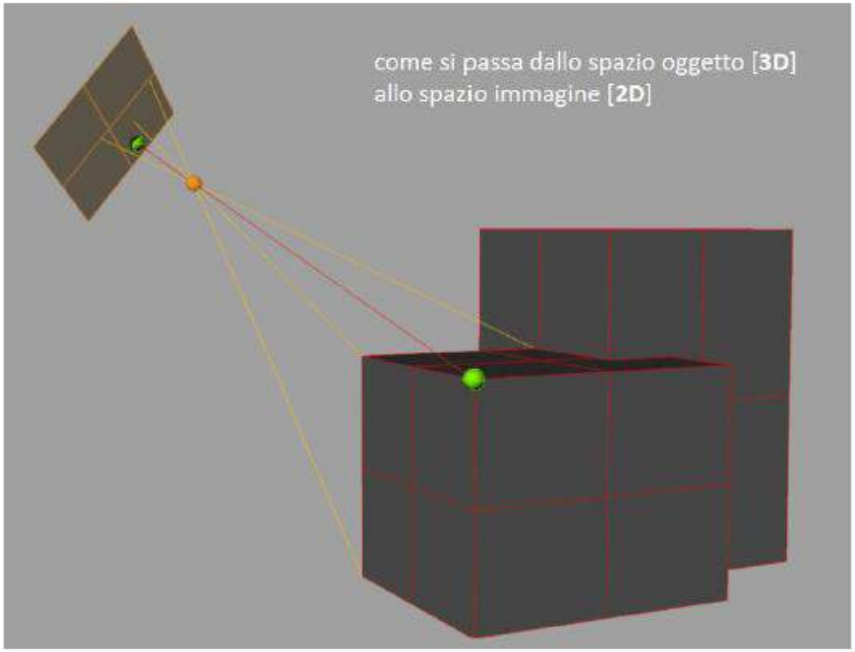
Maps



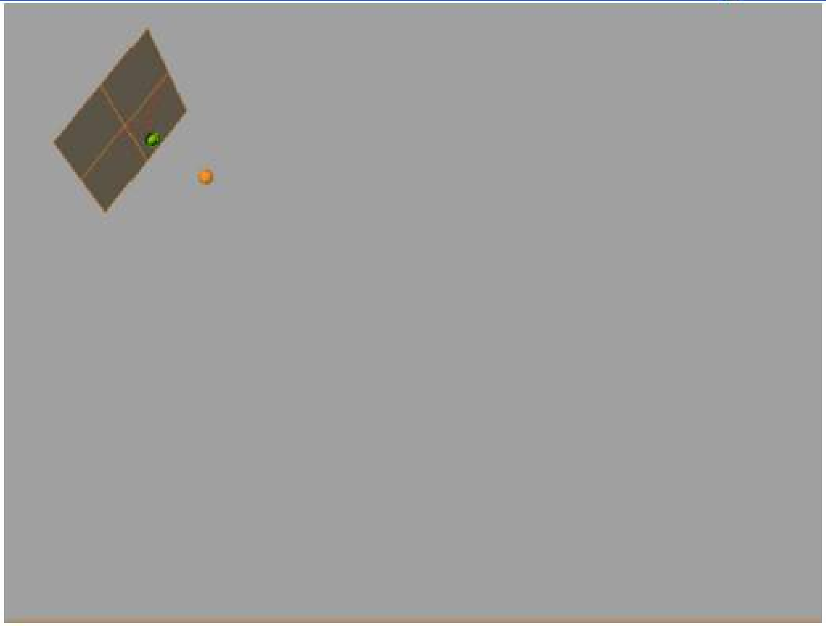
Principles

- A photo is a perspective representation of the object
- A central projection is obtained by projecting the object points on one plane, (projection plane), from a point outside it (center of projection).
- The straight lines joining the points the object with the center of projection are called projecting lines.
- Their points of intersection with the projection plane constitute the projections or "Images" of the points of the object.





- From the [2D] image space how we can go to the object space [3D]?



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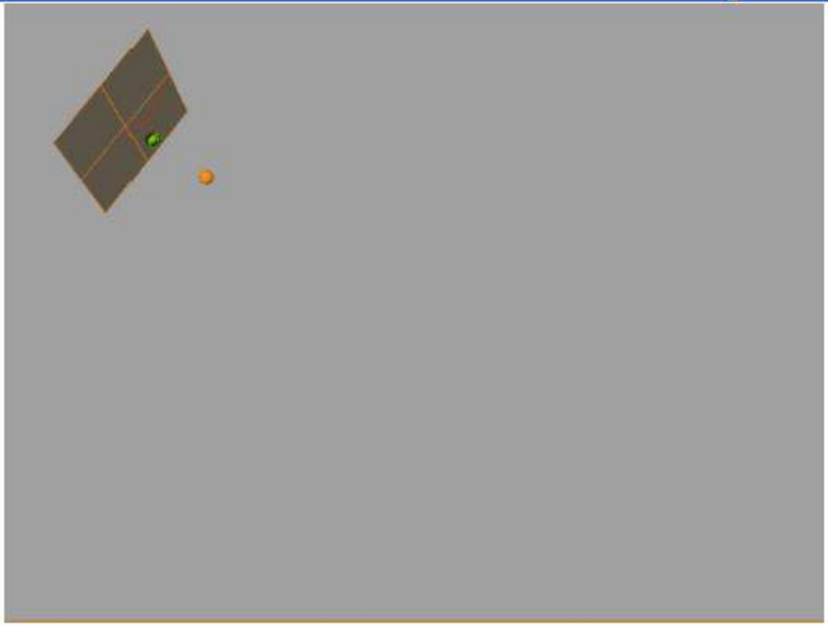
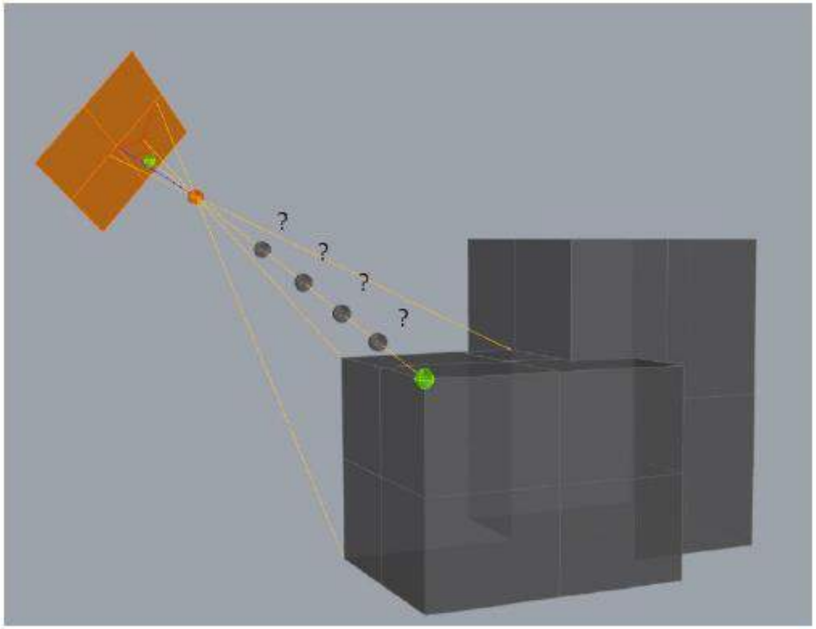
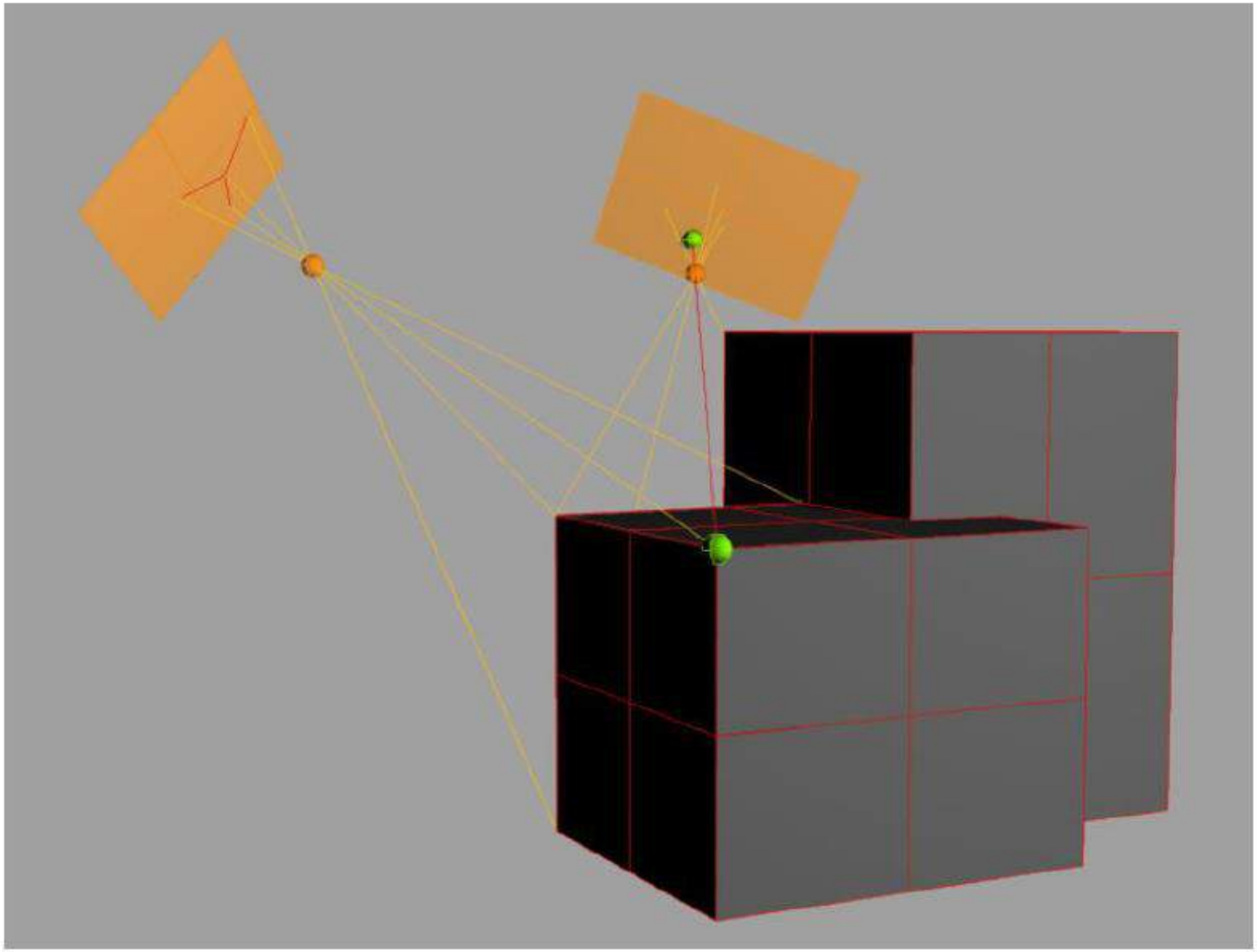


- The process, starting from just one frame, it is not generally possible
- At every point on the photograph correspond infinite points (all those on the projecting line)



Principles

- From the [2D] image space how we can go to the object space [3D]?
- By using two frames it is possible to solve the problem



Collinearity condition

- The exposure station of a photograph, an object point and its photo image all lie along a straight line.

Collinearity equations:

$$x_a = x_o - f\left[\frac{m_{11}(X_A - X_L) + m_{12}(Y_A - Y_L) + m_{13}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right]$$

$$y_a = y_o - f\left[\frac{m_{21}(X_A - X_L) + m_{22}(Y_A - Y_L) + m_{23}(Z_A - Z_L)}{m_{31}(X_A - X_L) + m_{32}(Y_A - Y_L) + m_{33}(Z_A - Z_L)}\right]$$

Where,

x_a, y_a are the photo coordinates of image point a

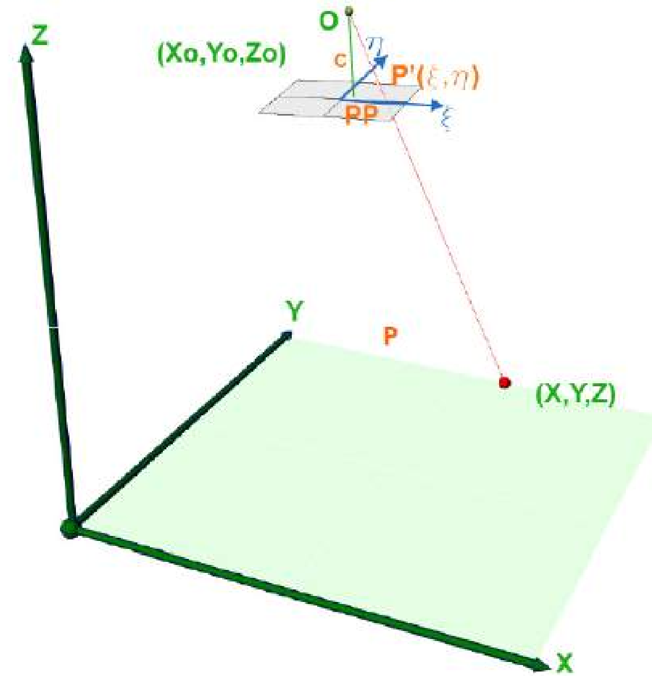
X_A, Y_A, Z_A are object space coordinates of object/ground point A

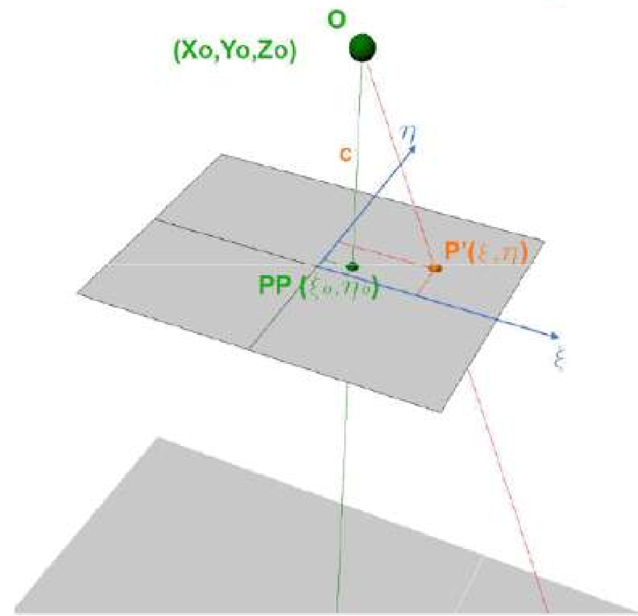
X_L, Y_L, Z_L are object space coordinates of exposure station location

f is the camera focal length

x_o, y_o are the offsets of the principal point coordinates

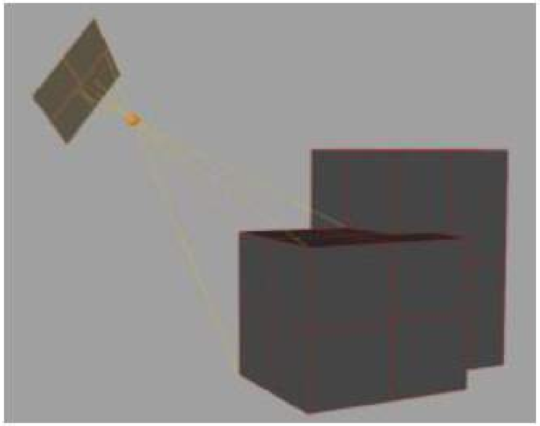
m's are functions of rotation angles omega, phi, kappa





Steps

- Image acquisition
  - from 3D object space to 2D image space through a central projection



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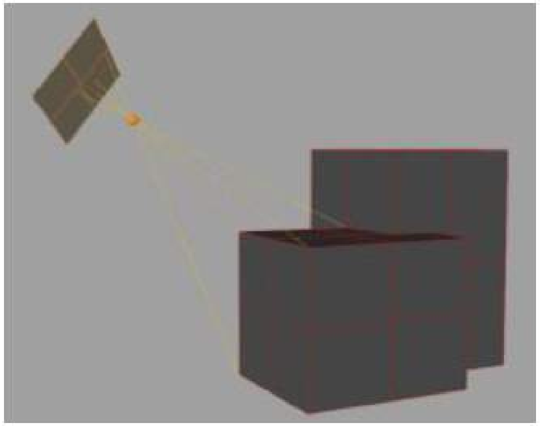
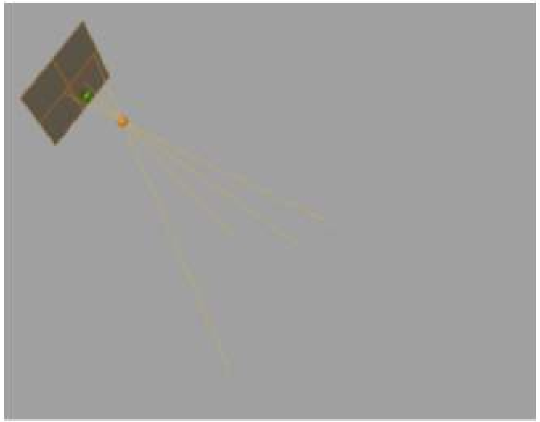


- Image orientation
  - reconstruction of the position of the camera



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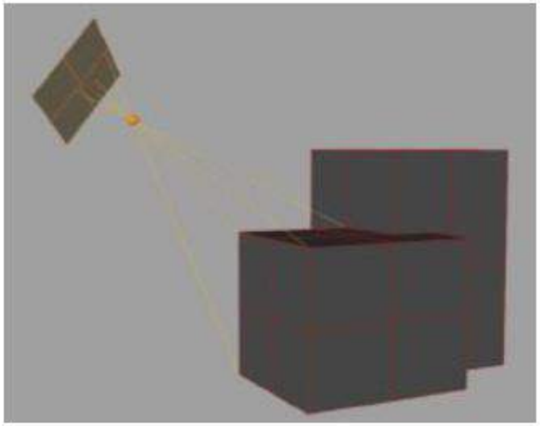

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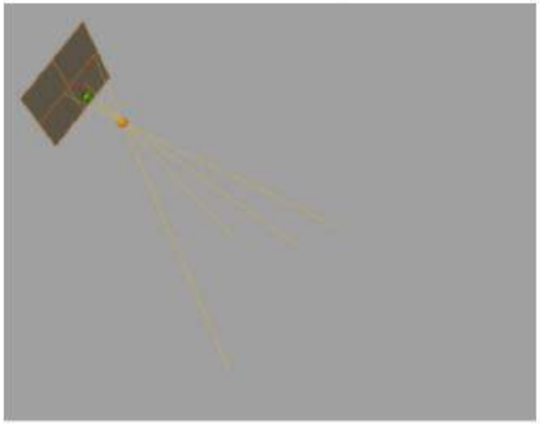


- Object reconstruction
  - reconstruct 3D geometry starting from 2D images

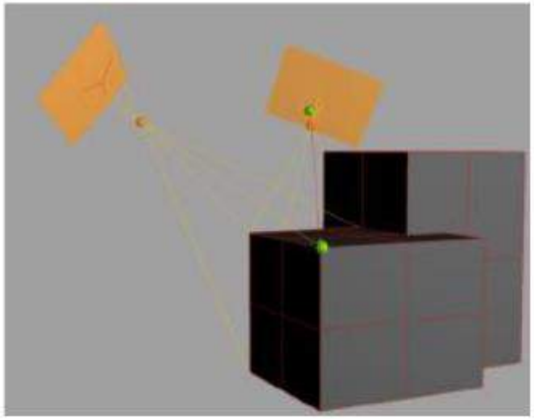
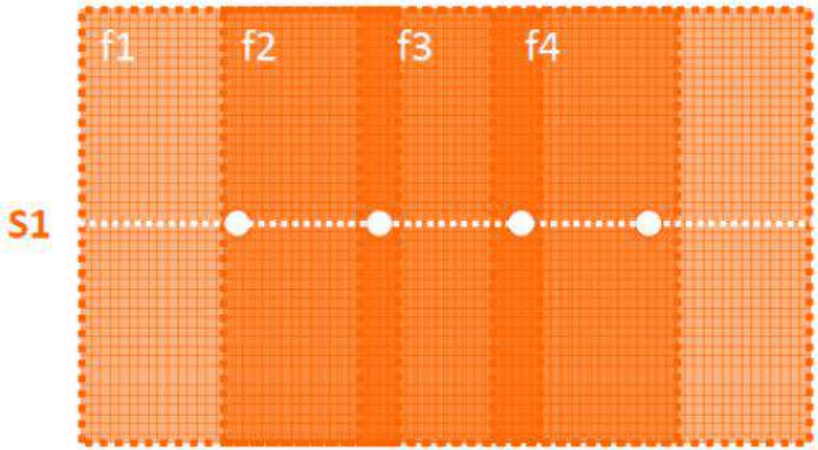
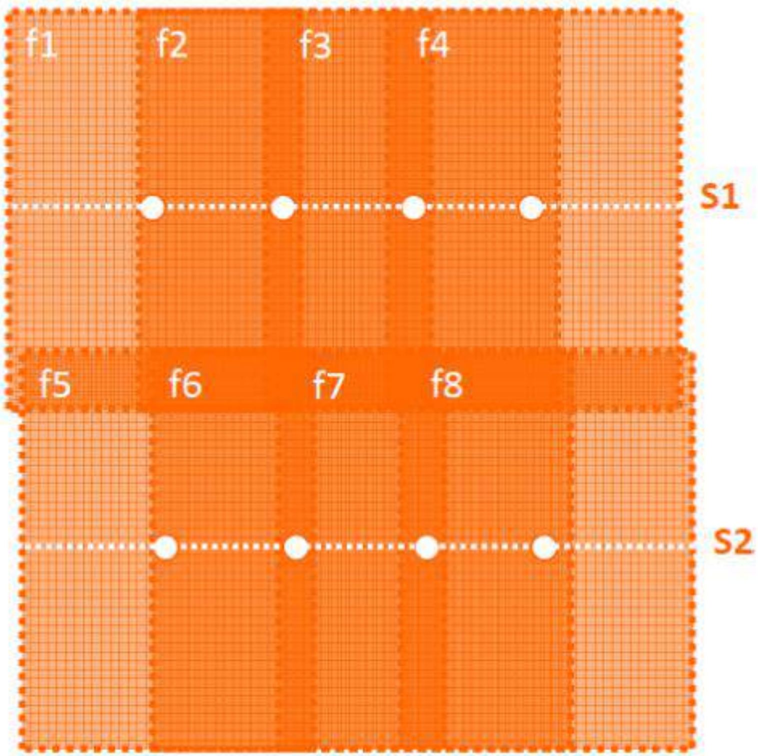


Image acquisition

- Image acquisition

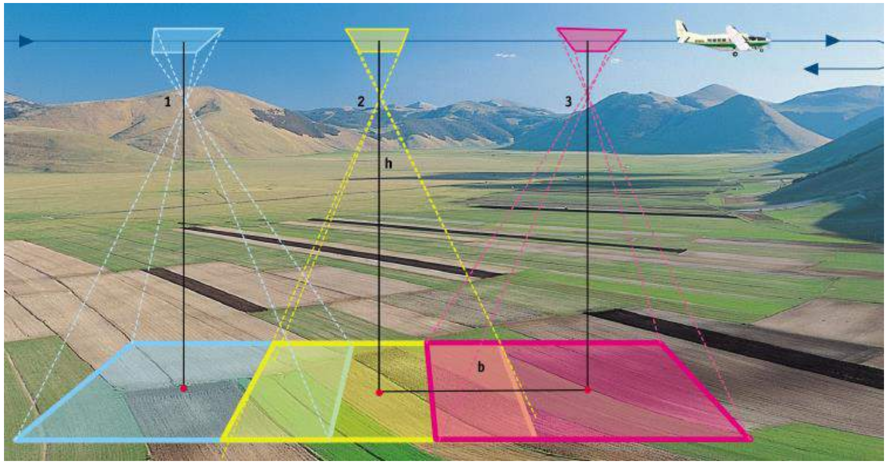


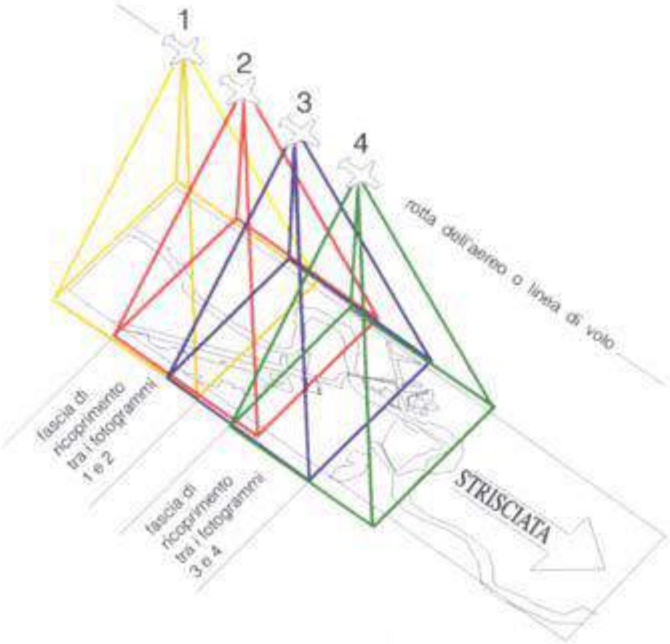
Photogrammetric strip: sequence of frames that are covered partially according to the direction of the strip (min 80%)



Photogrammetric block: sequence of strips with transverse overlap (min 40%)

Image acquisition





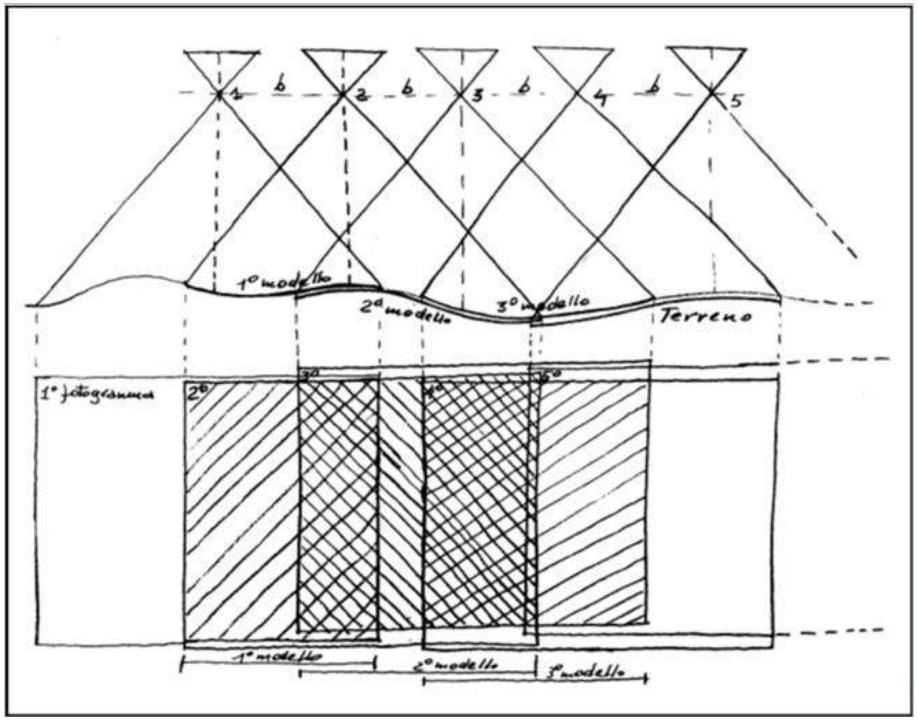


Image orientation

Compared to the theoretical mathematical-geometric model (central projection) it is necessary take into account that:

- the center of projection is not a point due to the nature of the lens system
- the projection frame is not a plan e due to deformations of film or sensor
- the projecting lines are not straight due to the distortion

The Brown–Conrady model takes into consideration those aspects with the following formula:

$$x_u = x_d + (x_d - x_c)(K_1 r^2 + K_2 r^4 + \cdots) + (P_1(r^2 + 2(x_d - x_c)^2) + 2P_2(x_d - x_c)(y_d - y_c))(1 + P_3 r^2 + P_4 r^4 \cdots)$$

$$y_u = y_d + (y_d - y_c)(K_1 r^2 + K_2 r^4 + \cdots) + (2P_1(x_d - x_c)(y_d - y_c) + P_2(r^2 + 2(y_d - y_c)^2))(1 + P_3 r^2 + P_4 r^4 \cdots),$$

where:

(x_d, y_d) = distorted image point as projected on image plane using specified lens,

(x_u, y_u) = undistorted image point as projected by an ideal pinhole camera,

(x_c, y_c) = distortion center (assumed to be the principal point),

K_n = n^{th} radial distortion coefficient,

P_n = n^{th} tangential distortion coefficient,

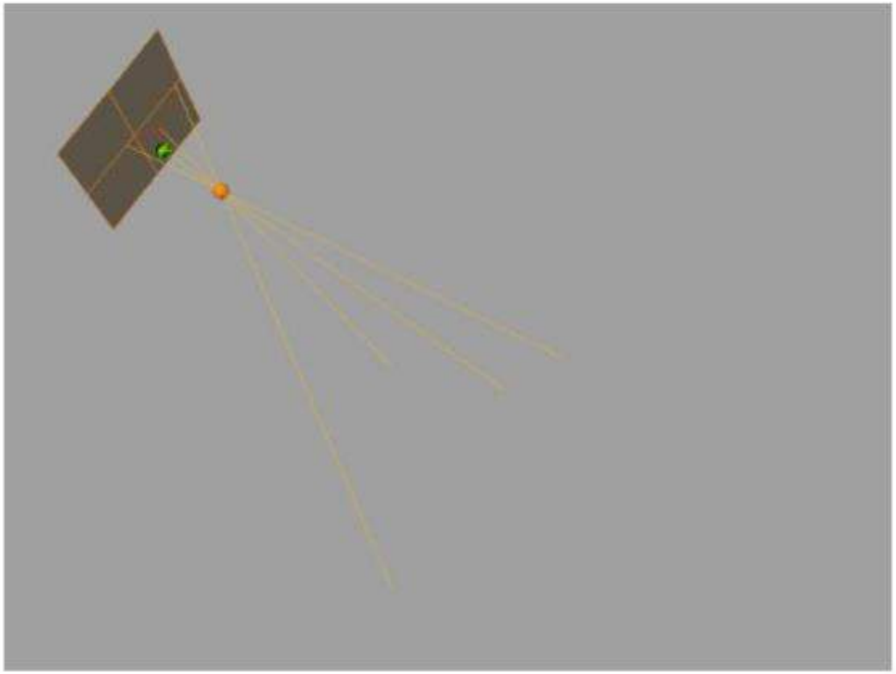
$r = \sqrt{(x_d - x_c)^2 + (y_d - y_c)^2}$, and

$\ldots$ = an infinite series.

Image orientation

The position of two (or more) projecting rays must be determined so that their geometry is the same they had when images were taken.

Thus one can reconstruct the geometry of the object photographed through the intersection of corresponding projecting rays.



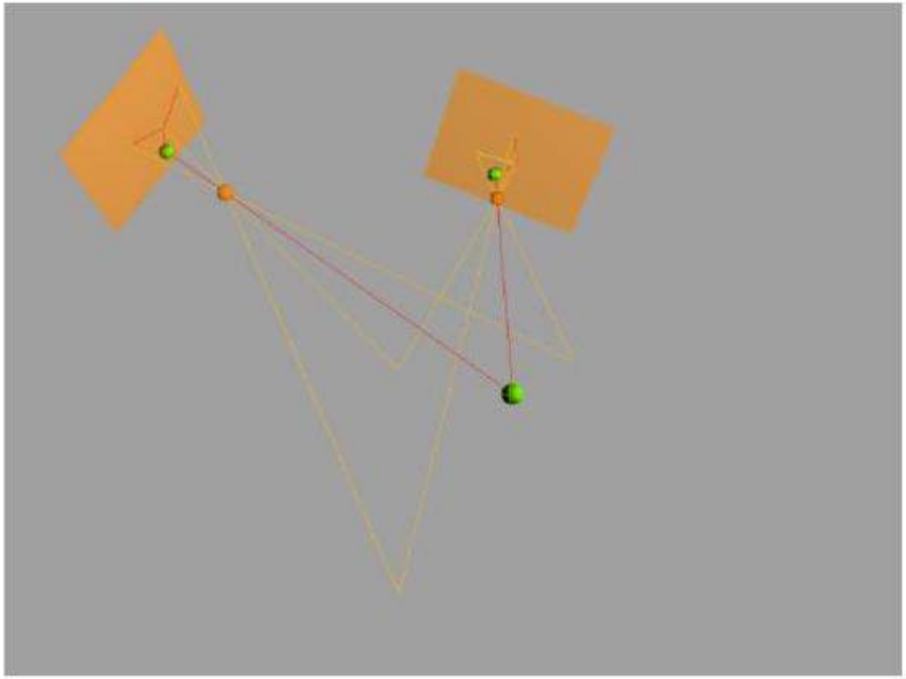
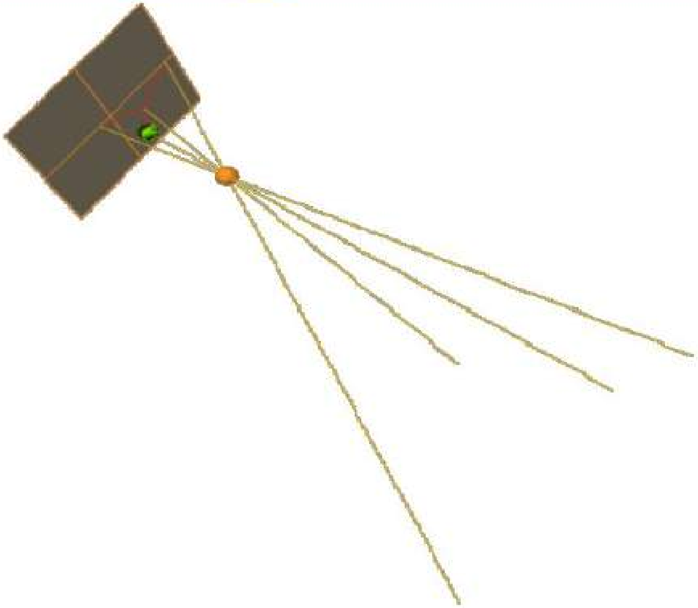


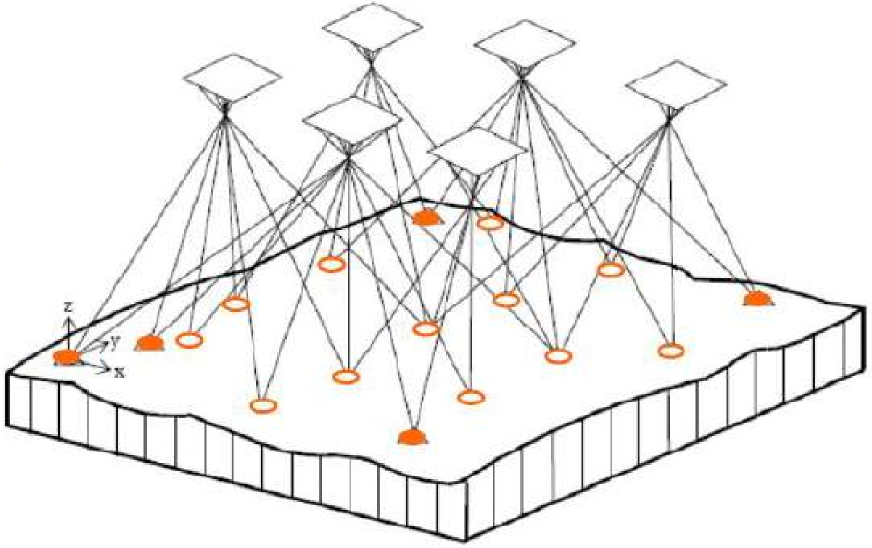
Image orientation



The image points and the projection center of each frame define a bundle of rays.

The external orientation parameters of all the bundle in the block are calculated simultaneously, thanks to:

- image coordinates + object coordinates of the ground control points (to **be measured)**
- image coordinates of corresponding (tie) points in two or more photos

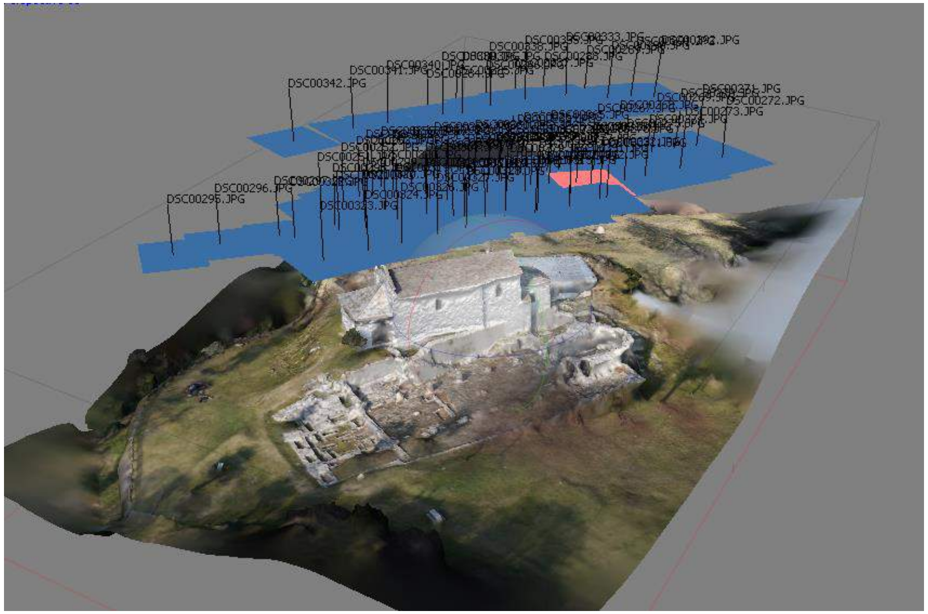


In compensation the bundle ray are translate and rotate so that the rays

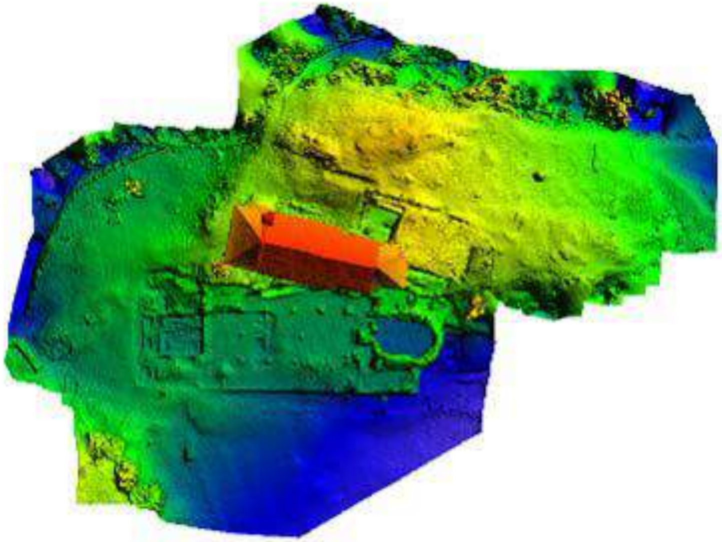
- intersect at the best at the corresponding points (tie points)
- are close as much as possible to the ground control points

Object reconstruction

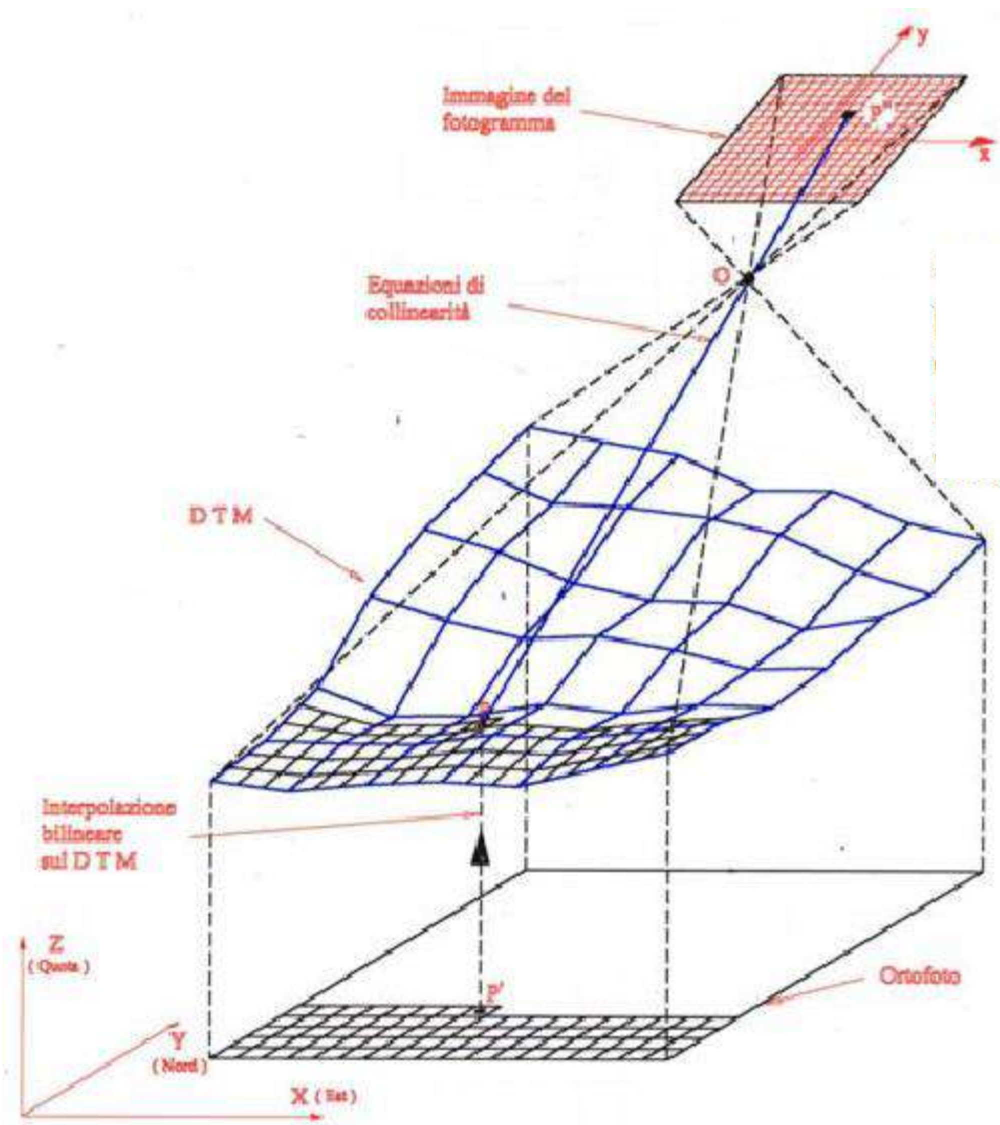
Given the position of the cameras the reconstruction of 3D geometry is performed.



This information can be used for production of Digital Surface Model (DSM) or a Digital Terrain Model (DTM).

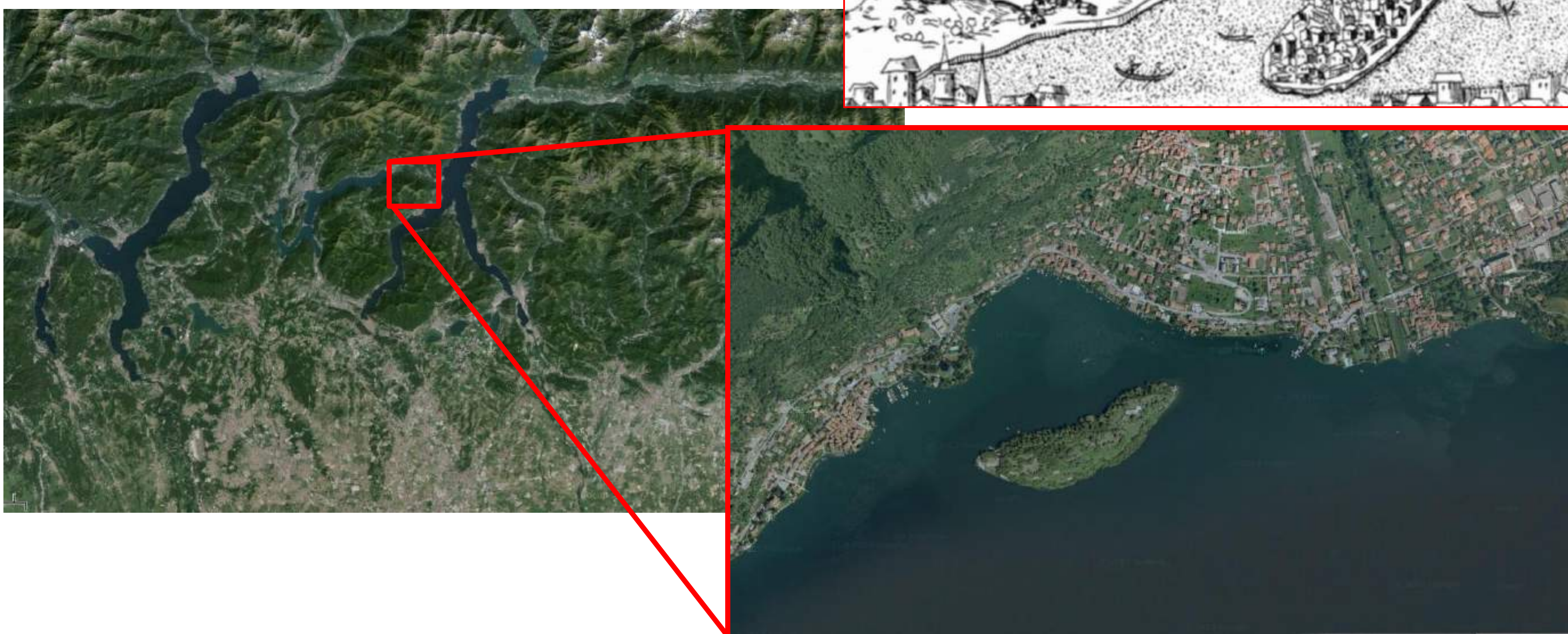


An orthophoto (or orthoimage) is an image geometrically corrected («orthorectified») such that the scale is uniform: the photo has the distortion as a map.



Example

- Island located in the Lago di Como (Lombardy, Italy)
- Archaeological traces Roman and early Christian times
- Middle Ages the island was the center of military (fortified town) and of religious events
- Remains of the numerous religious structures
- Abrupt abandonment of the island in 1169



Example

- Micro-UAV for surveys at territorial/local scale
- ASCTEC Falcon 8 (70 cm x 60 cm, weight 2 kg)
- Cameras
  - Sony NEX-5N (4912 x 3264, focal length 16 mm)

Site	RGB	
	Flight heigth	Ground resolution
St. Eufemia (Site A)	35 – 55 m	1 cm
St. Eufemia (Site B)	35 – 55 m	1 cm
St. Pietro	45 – 60 m	1.3 cm
Hilltop	-	-

Example

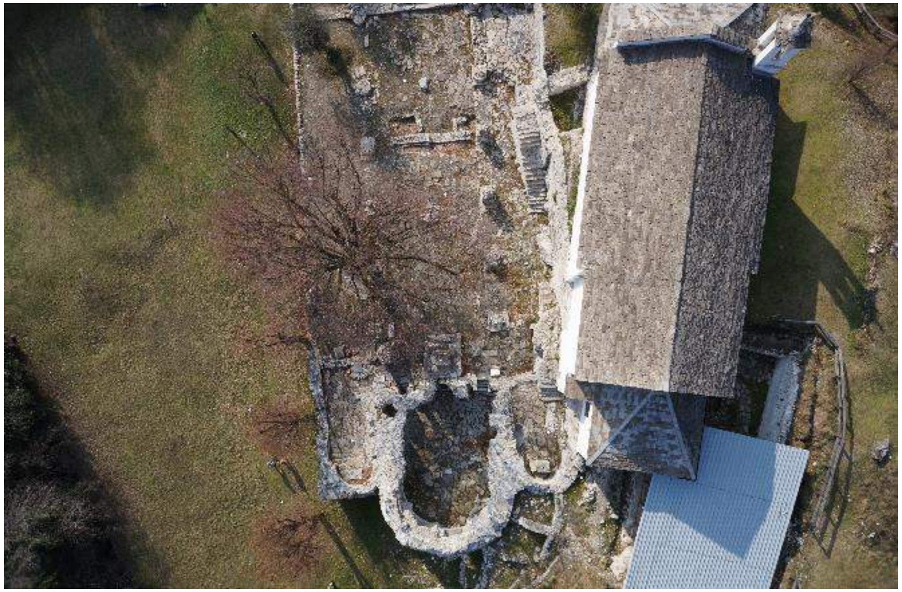
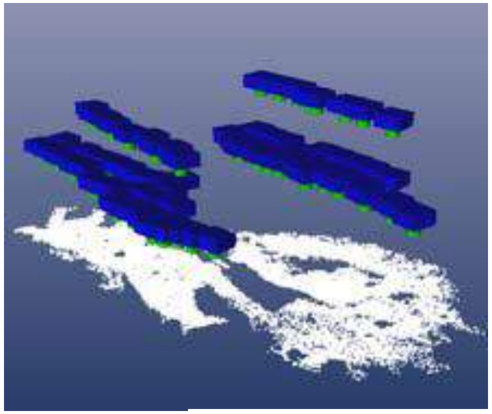


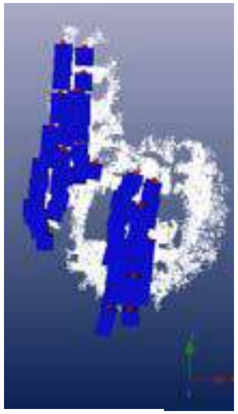
Image detail

Example

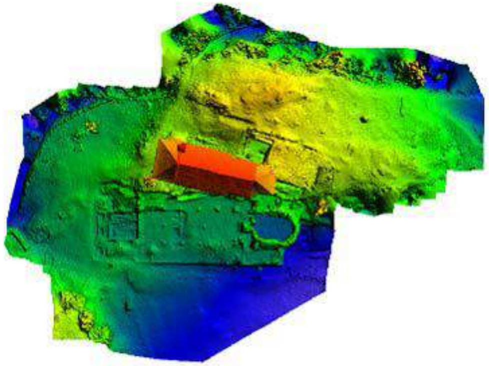
Results

Orientation





DSM



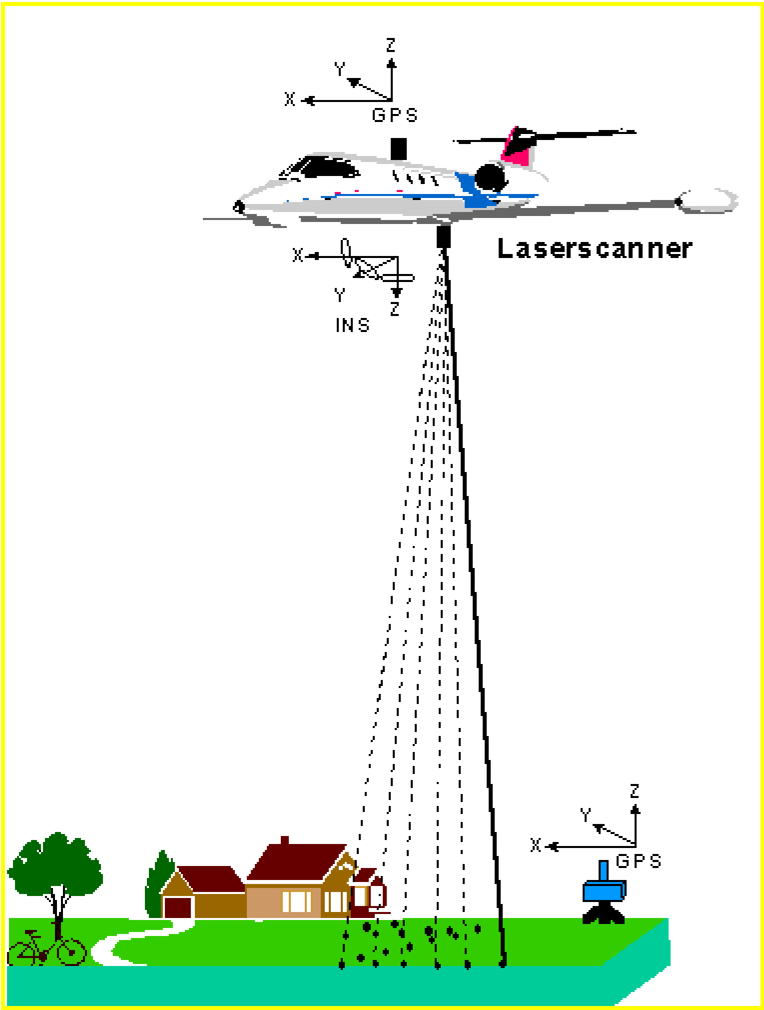
Orthophoto

Example

Video

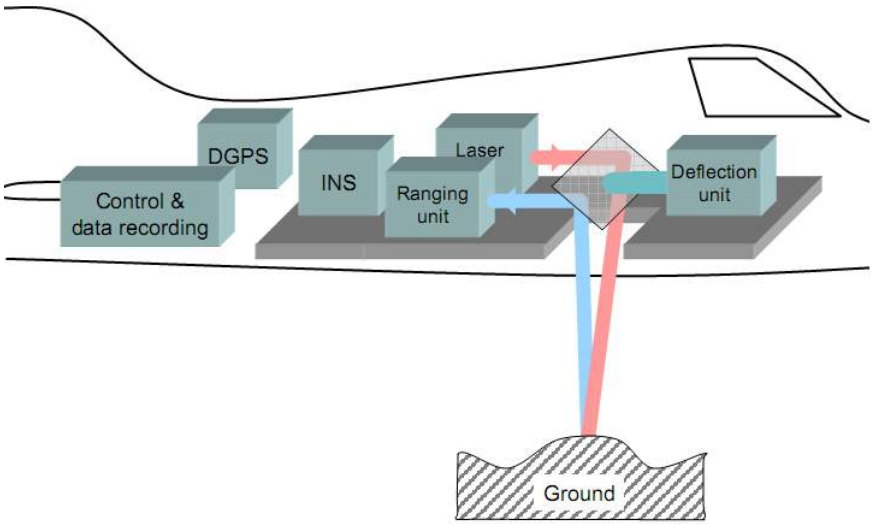
LIDAR

LiDAR = Light Detection and Ranging



The system consists of:

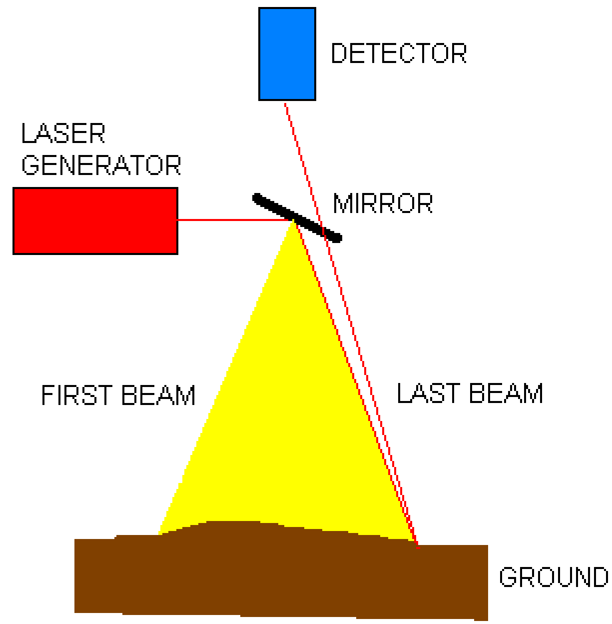
- a LASER to measure distances;
- a GPS and an INS to determine the position and set-up

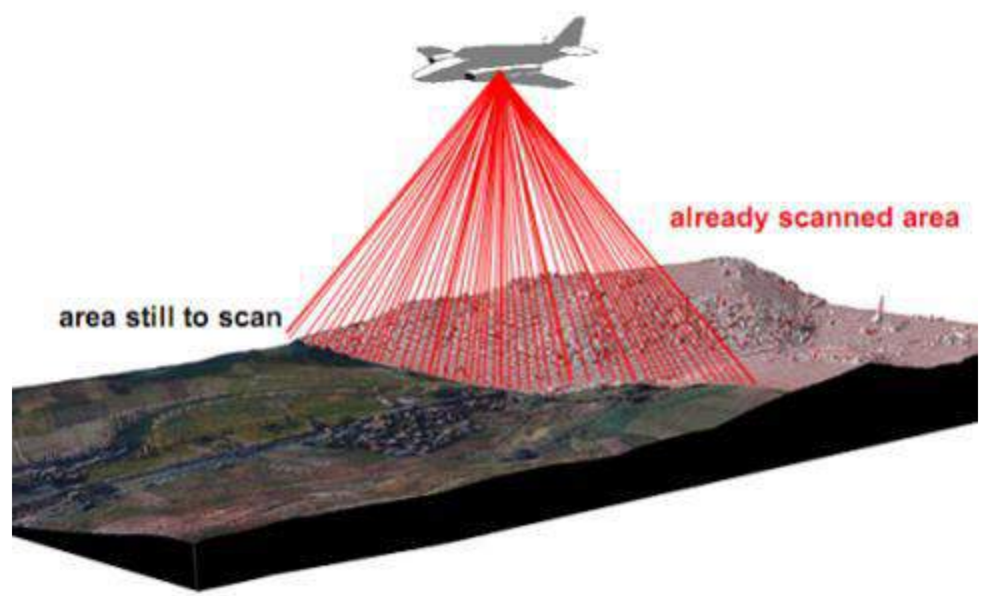


Data acquisition

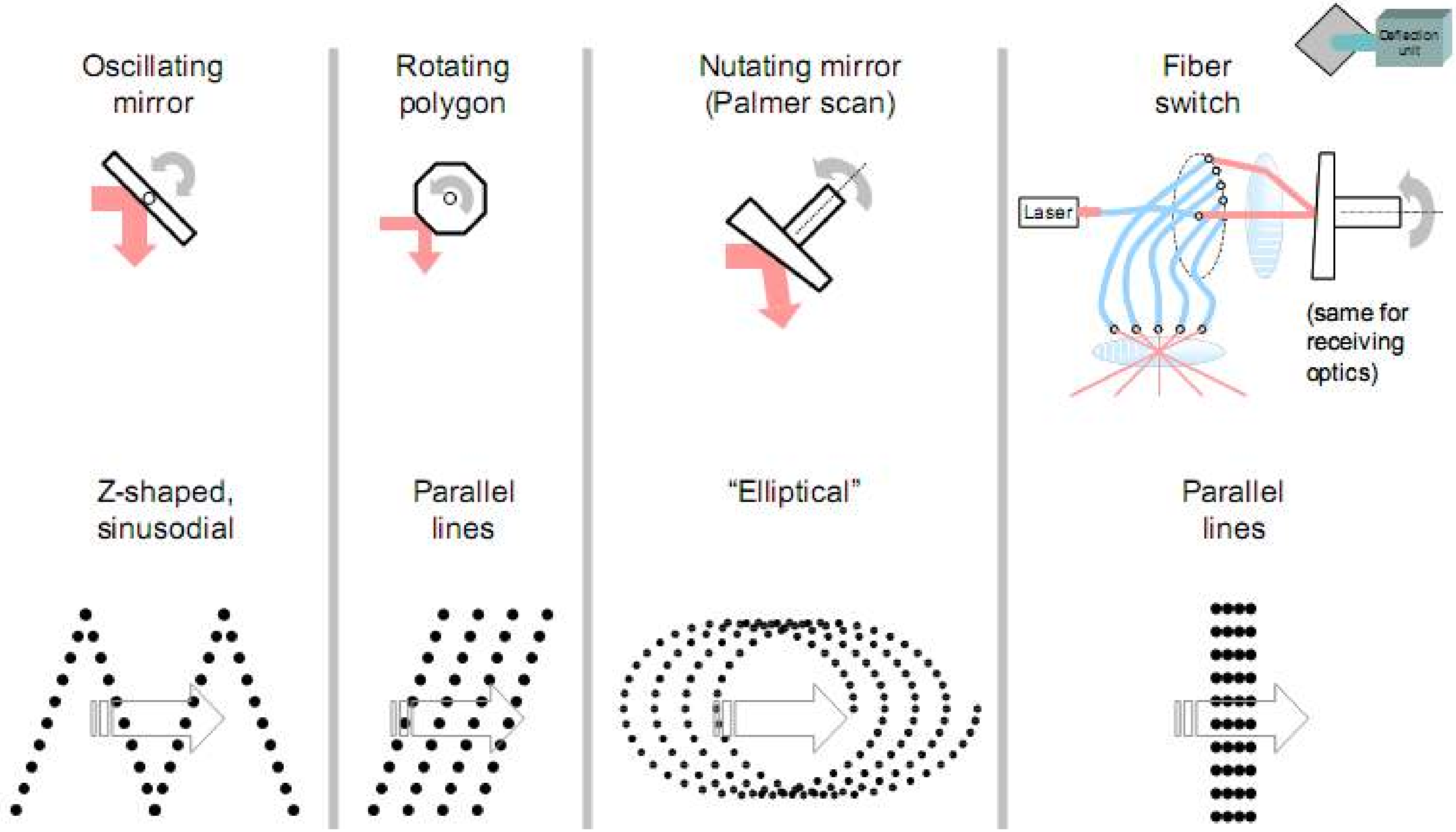
- sending the pulse:
- the impulse is deflected by the rotating mirror;
- the impulse is reflected by the ground and then received by a detector on the plane
- a high precision clock evaluates the flight time of the signal;
- from the time measure, I obtain the distance:

  $d = v\, t / 2$

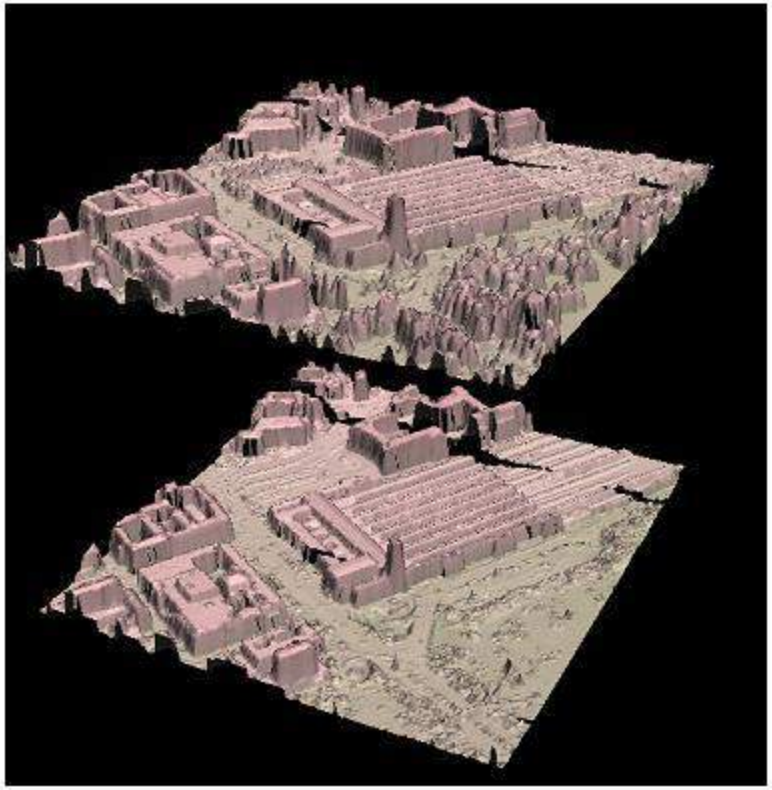




Rotating mirror



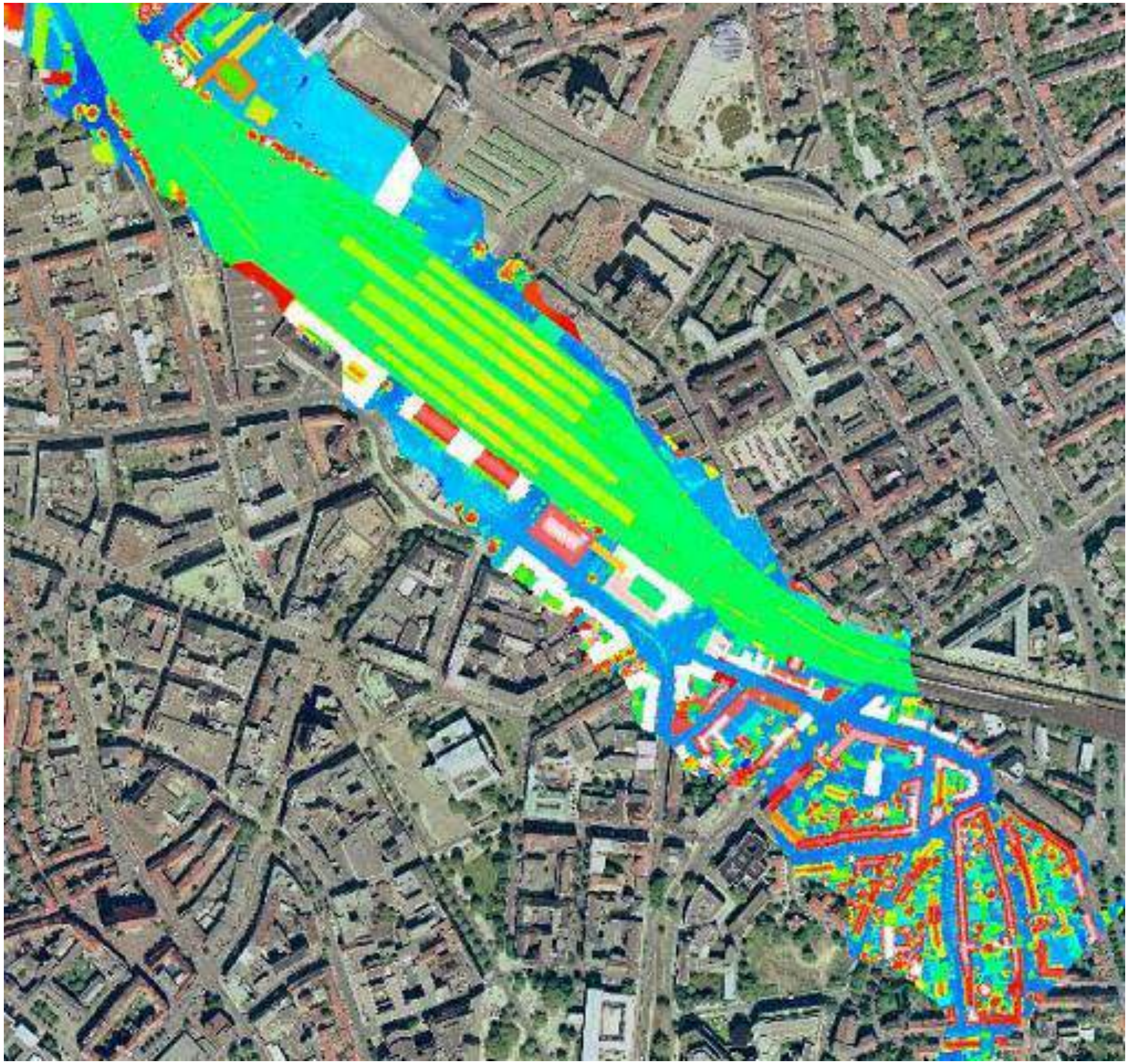
The reflected impulses

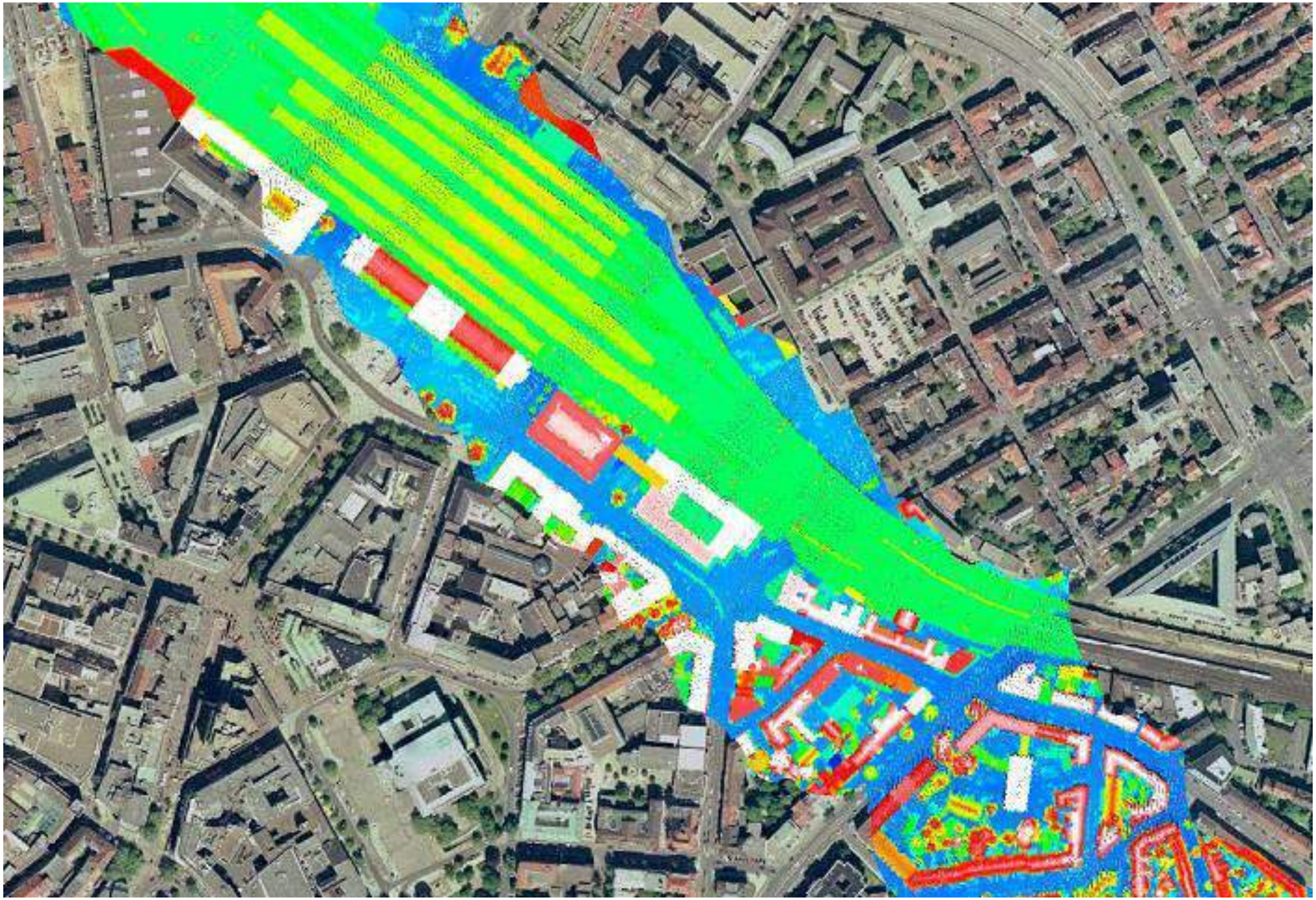


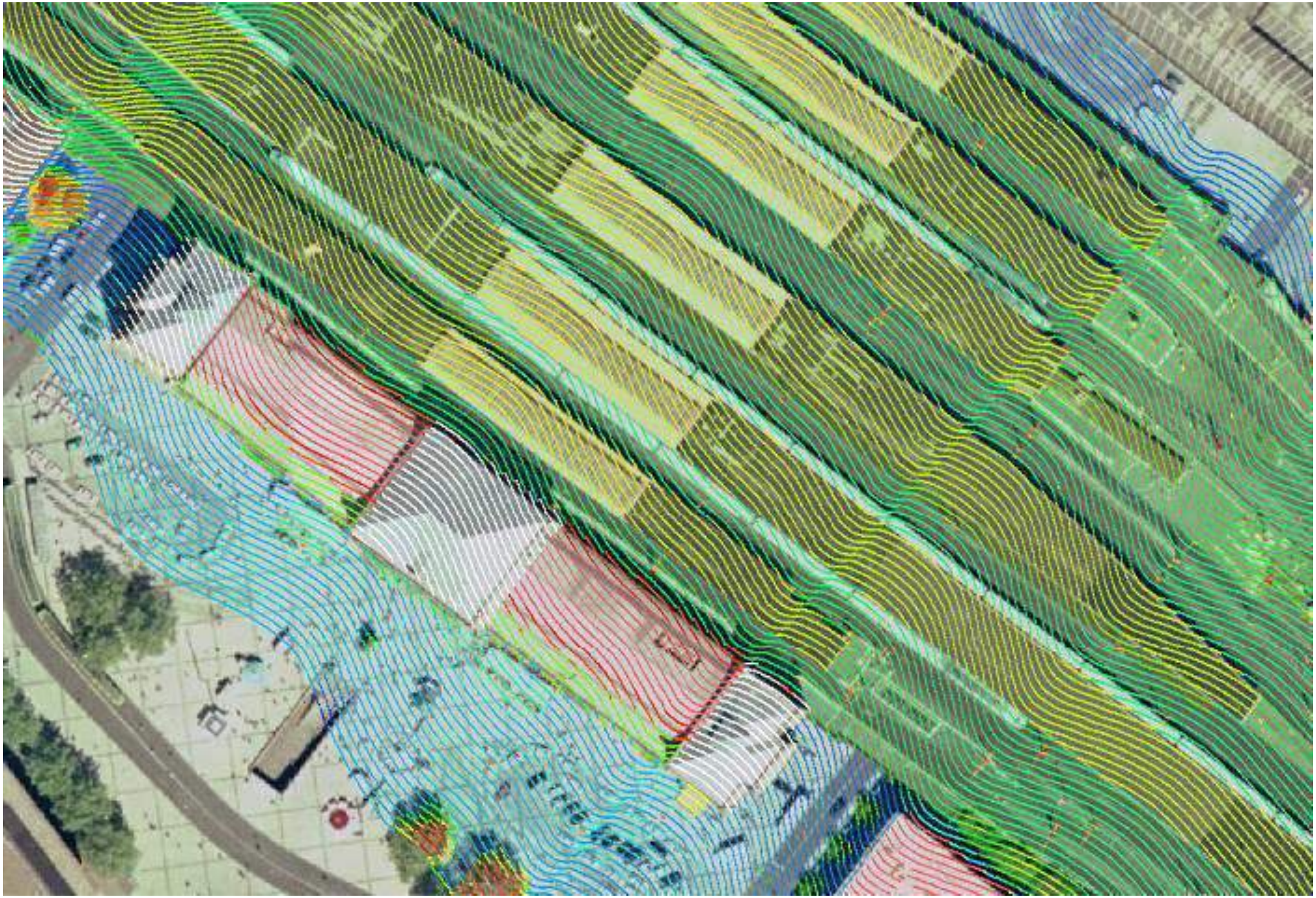
First

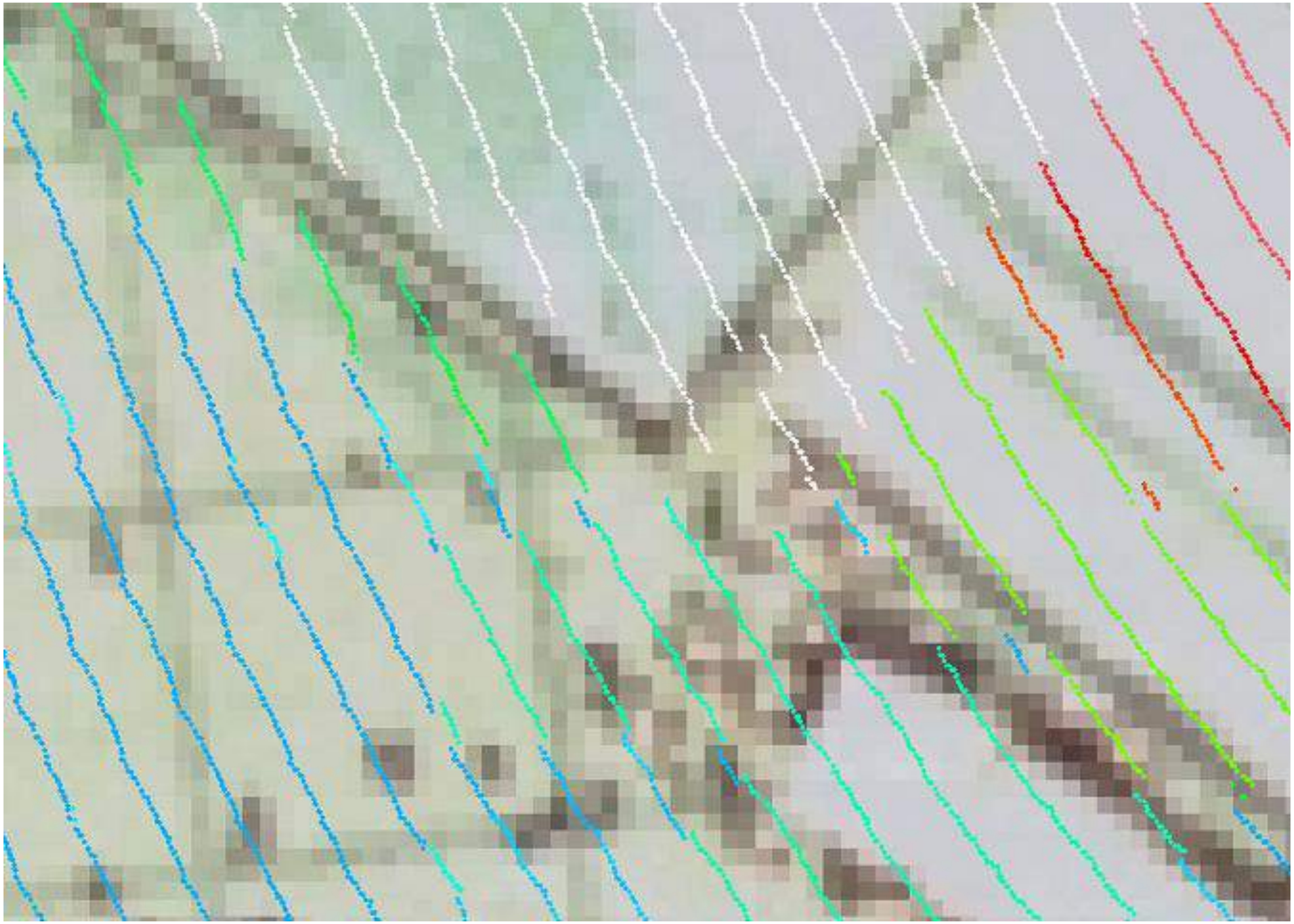
Last

TopoSys raw data









1 pixel = 0.4 x 0.4 m2

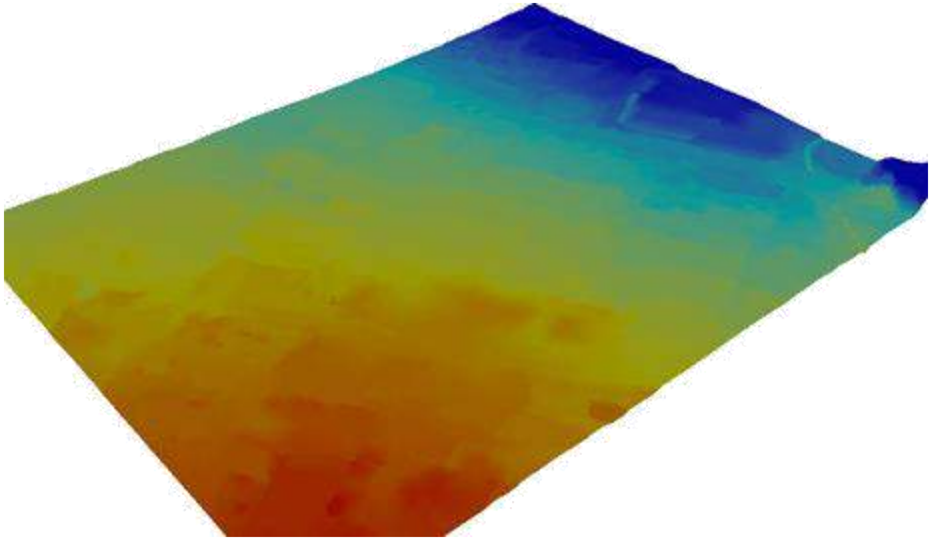
Purpose of a LiDAR flight → creation of DTMs and DSMs

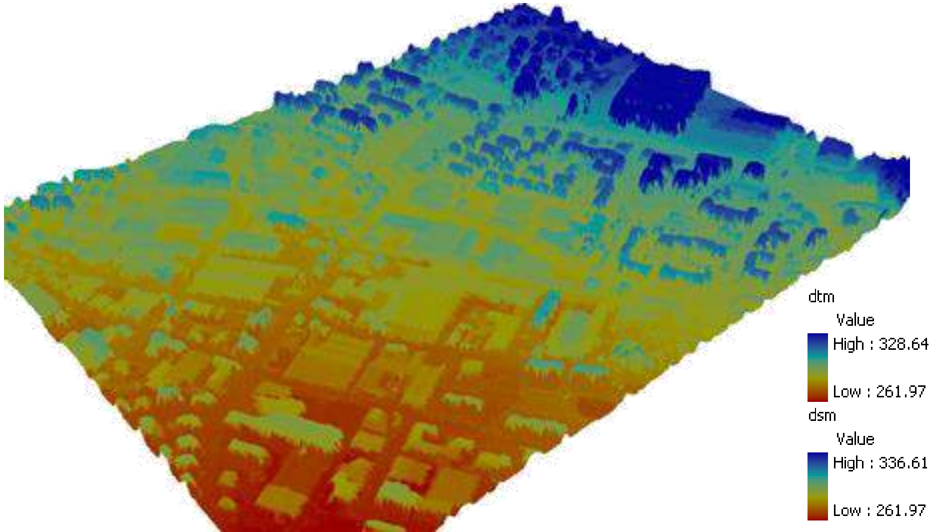
Numerical models representing the trend of the ground or surface

- The objective of the DTM is a completely 3D management of the morphology of the territory

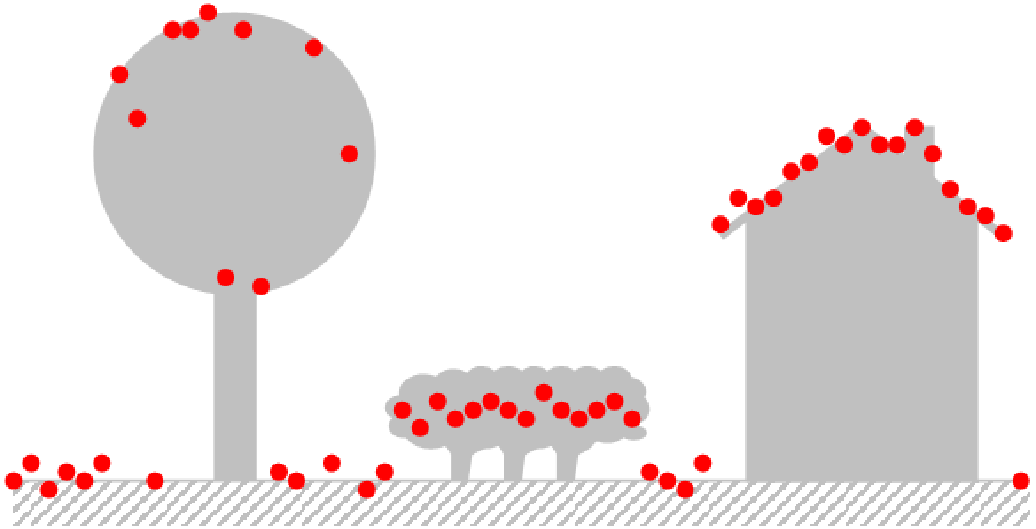
- Pay attention to the difference between DTM and DSM (or even DOM) - T = Terrain, S = Surface, O = Object

- Objectives of the DTM: make analysis on the form (eg hydraulic model), orthorectify the images

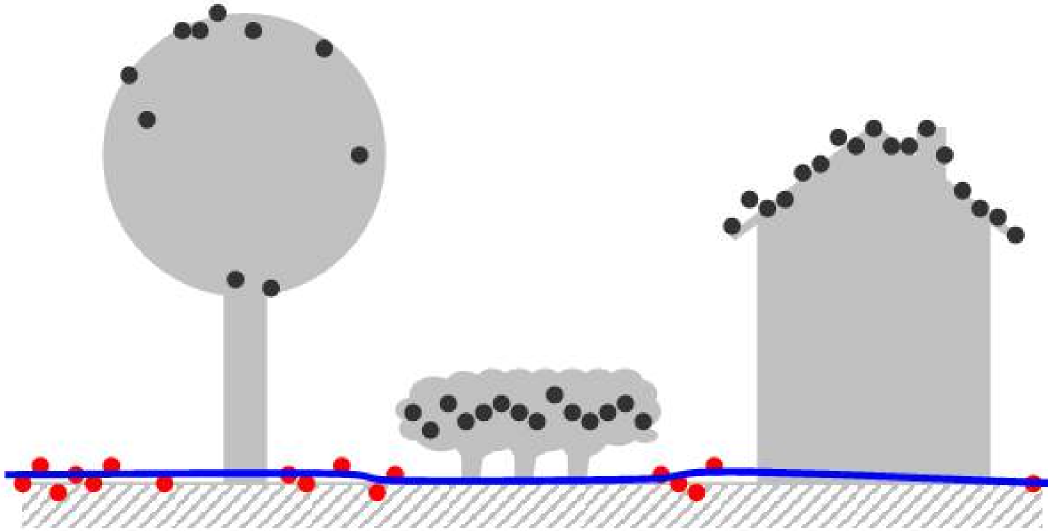




DSM



DTM



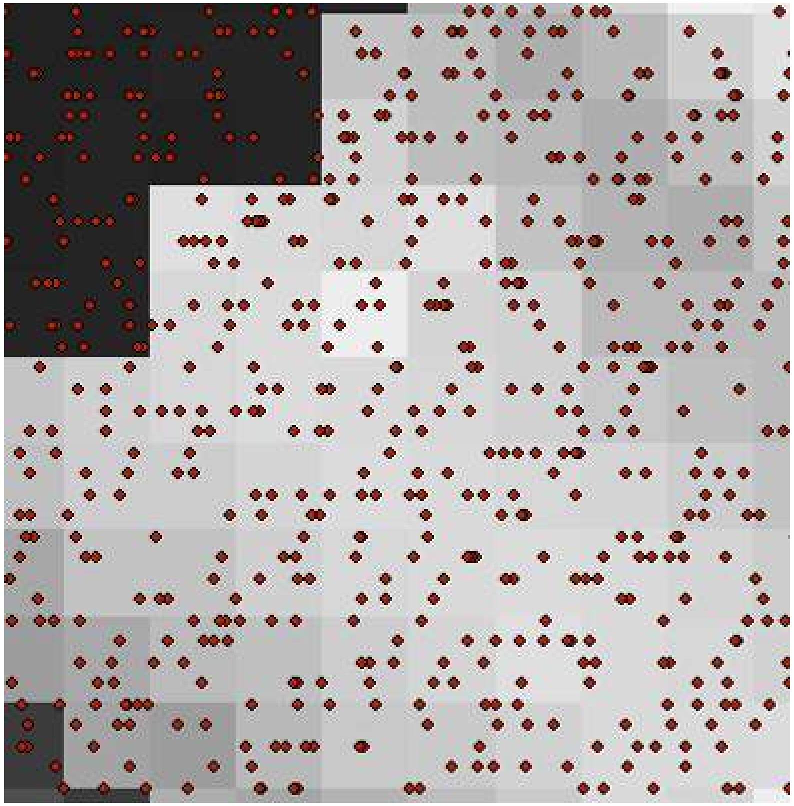
Result of data acquisition

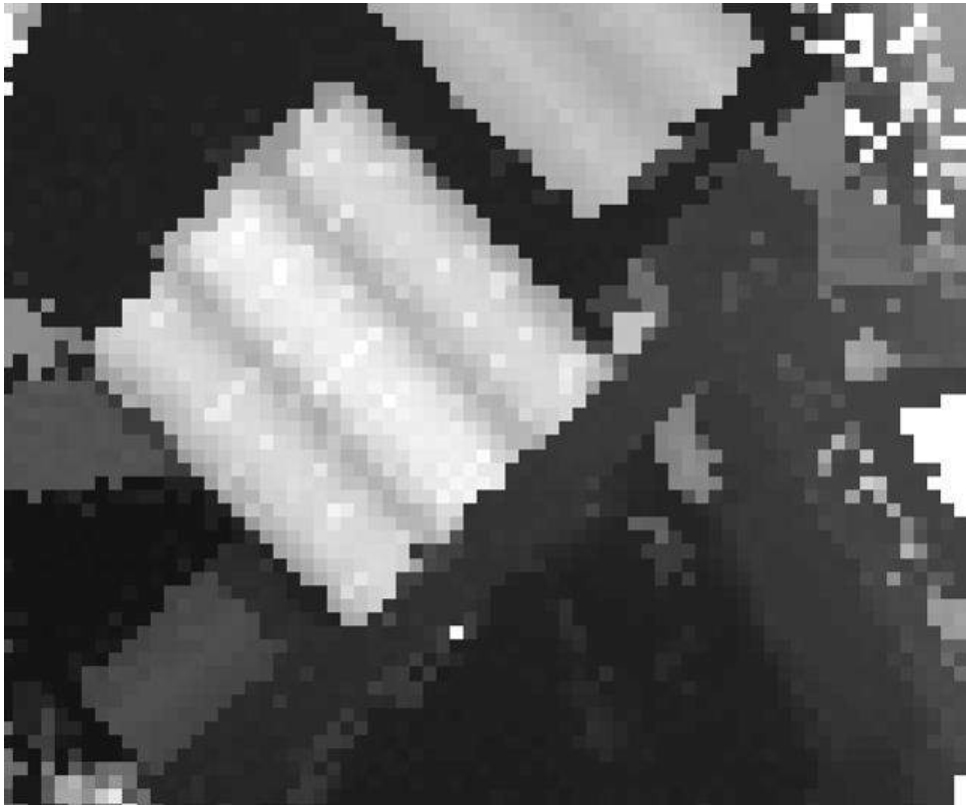
- A single point file X, Y and Z
- Possible file of object contours (of the lake, of the detected area, ...)
- The level of accuracy of these points
- The average density (per unit of area) of the points detected
- Information is discreet
- There is still no continuation
- Memory occupation equal to the number of points detected for the memory occupation of a single point

Types of DTMs / DSMs

GRID = regular grid format in which the model is stored as a matrix

The model is obtained by interpolating the measured points on a regular grid (generally square cells)



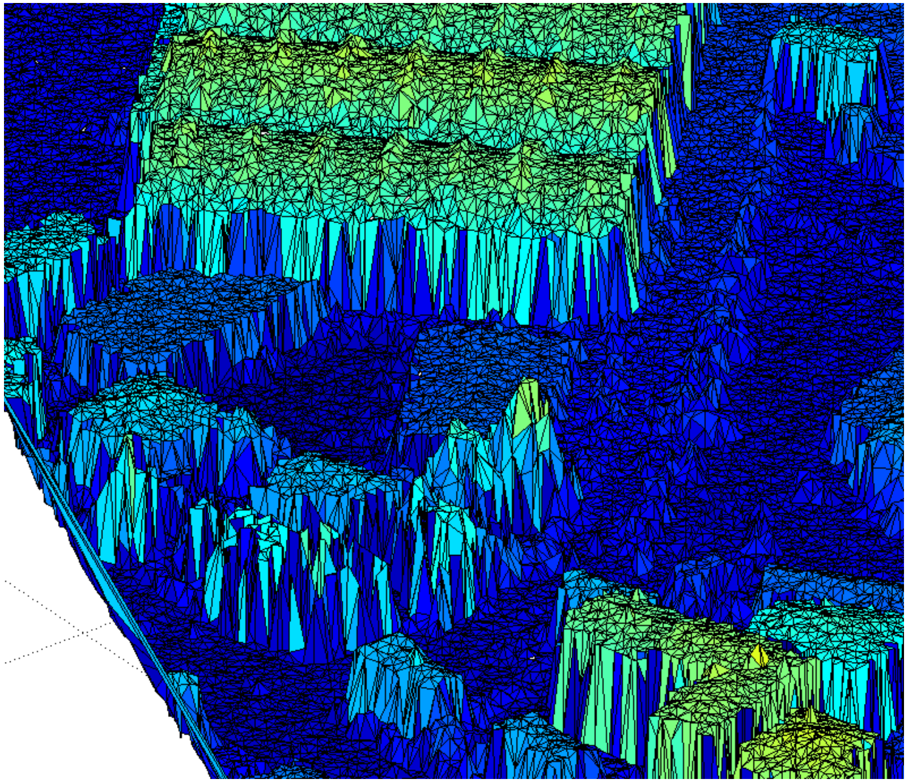


The resolution of the DTM / DSM obtained by LiDAR is generally 1m x 1m or 2m x 2m

Types of DTMs / DSMs

TIN (Triangulated Irregular Network) = formed by connecting the points through a network of triangles (preserving the original data)

Each point detected is the vertex of a triangle



The resulting triangles are as much as possible equilateral and do not overlap