## 1. Photogrammetric solution

As stated previously, digital photogrammetry is used for many applications, ranging from:

- Orthorectification,
- Automated elevation extraction,
- Stereopair creation,
- Feature collection,
- Highly accurate point determination and,
- Control point extension.

For any of the tasks mentioned above to be undertaken, a relationship between the camera/sensor, the image(s) in a project, and the ground must be defined.

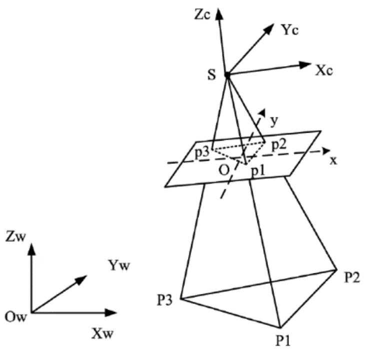
The following variables are used to define the relationship:

- Interior orientation parameters for each image.
- Exterior orientation parameters for each image.
- Accurate representation of the ground.
- Well-known obstacles in photogrammetry include defining the interior and exterior orientation parameters for each image in a project using a minimum number of GCPs.

The method used to find the interior and exterior orientation are:

### 1. Space resection

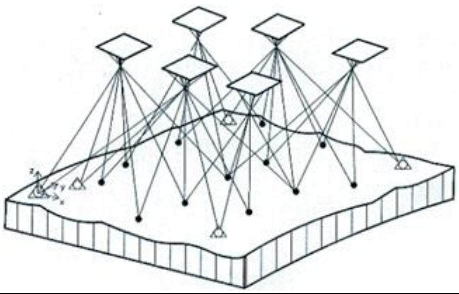
- Is the determination of an image's position (X,Y,Z) and orientation parameters (phi, kappa, lymda) concerning an object space coordinate system. Or known as the exterior orientation parameters associated with one image or many images based on known GCPs. Using the collinearity condition



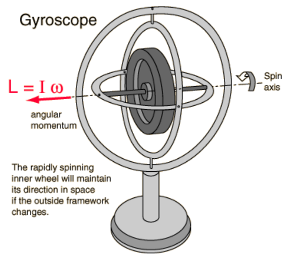

### 2. Aerotriangulation

Triangulation is the process of orienting and registering images to the ground to create a rigorous sensor model. Images are more accurate after triangulation. Accuracy is achieved through measuring image coordinates using ground control points, tie points, and terrain files.

For large mapping projects, the number of control points is extensive, and the cost of establishing them can be extremely high if it is done extensively by field survey methods. Therefore Aerotriangulation can densify or extend the GCP through the area, when used in the mentioned process, is called "bridging".



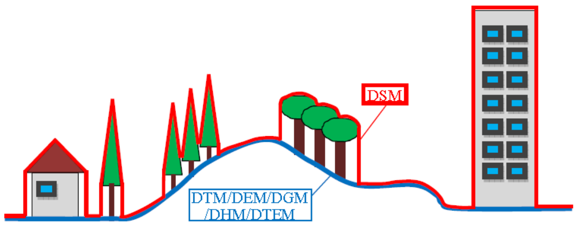
Currently, the aircraft uses GPS and INS/IMU (to the right), which helps to provide the camera with the coordinate and angular attitude of the camera the instant each photograph is exposed. However, in theory, this method can eliminate the need for GCP, although, in practice, a small amount of ground control is still used to strengthen the solution.


2. **DSM** is simply a statistical representation of the continuous surface of the ground by a large number of selected points with known X,Y,Z coordinates in an arbitrarily coordinated field.

**A DSM** is the elevation representation of both the terrain and the objects close to it (such as buildings, pylons and trees) represented digitally (numerically).

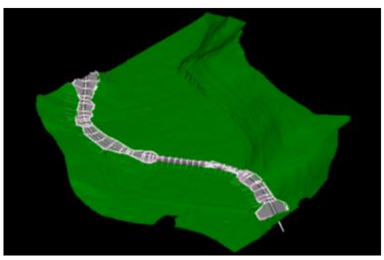
**A DTM** is the elevation representation of the terrain only, excluding the objects close to it.

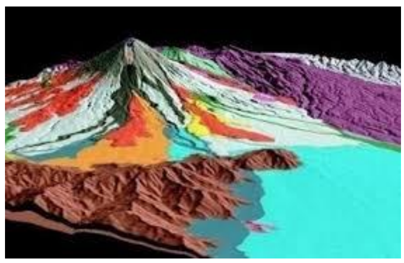



3. **DSM application:**

The application domains of DTMS include the following:

1. Civil Engineering, such as road design, railways, dams, reservoirs, buildings, landscaping, etc..
2. Earth sciences include climate impact studies, geological and hydrological modelling, geomorphology and landscape analysis, volcanic hazards, etc...
3. Remote Sensing and Mapping, DTM with GIS is used together to correct images or retrieve thematic information concerning sensor geometry and local relief to produce georeferenced products (Orthoimagery).
4. In military applications, it is a necessary product to be used to understand the terrain, elevation, and slope of the land surface. In addition, it produces a 3D display for weapon guidance, flight simulation, and radar line-of-sight analysis.

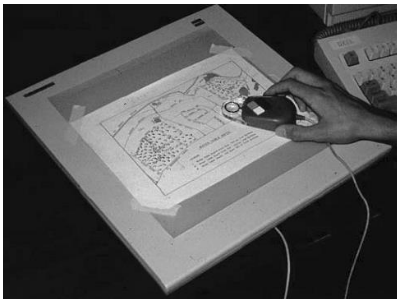




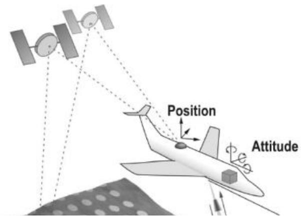
## 4. DTM/DSM Generation

DSM / DTM is produced from different applications such as:

a) Geodetic Survey: in this Survey, instruments such as Level, theodolite, total station, or RTK-GPS is used, and it is considered the most accurate DTM. Therefore, it is preferred to be used as a data source for validation or small-scale projects.



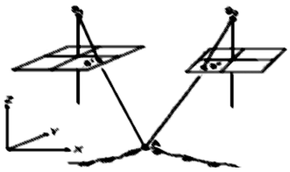
b) Cartographic Data Sources are based on digitizing topographic maps, is considered labour dependent and is conserved as the most popular method since the topographic maps are available for the large-scale area. The production of this method is based on DTM only



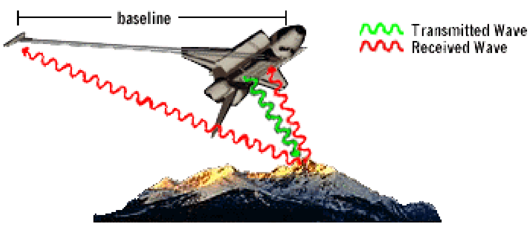

c) Airborne LiDAR Data stands for ***Light Detection And Ranging*** (to measure variable distances), is an active system it sends off electromagnetic energy (in the form of pulses) and records the energy scattered back from the terrain surface and the objects on the terrain surface.

a) A terrestrial laser scanning system (TLS) is a ground-based, active imaging method that rapidly acquires accurate, dense 3D point clouds of object surfaces by *laser* range finding.

b) Photogrammetric Data DSM is considered a remote sensing tool based on constructing the original shape of 3D model based on stereo pair images. And then measure the 3D coordinates of the object on the stereo model



c) Radar Based systems, such as synthetic aperture radar (SAR), or Shuttle radar topographic mission (SRTM). It is considered airborne or spaceborne. Imaging radar is an active sensor—that provides its illumination through microwaves. It receives and records echoes reflected by the target and then maps the intensity of the echo into a grey scale to form an image.



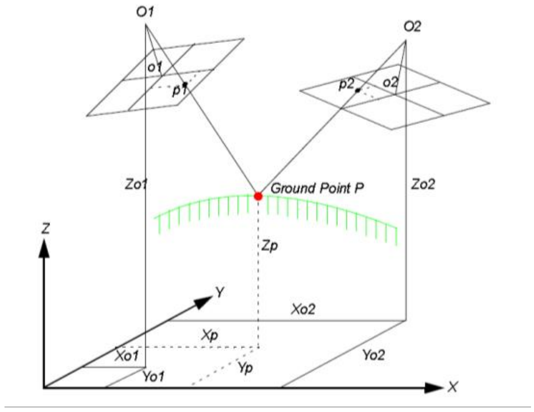

Radar signals being transmitted and recieved in the SRTM mission (image not to scale).

## 5. Obtaining 3D points from photogrammetry

**Or Space forward intersection** is a technique that is commonly used to determine the ground coordinates X, Y, and Z of points that appear in the overlapping areas of two or more images based on known interior and exterior orientation parameters—using the collinearity condition.

Using the collinearity equations, the exterior orientation parameters, along with the image coordinate measurements of point *p1* in Image 1 and point *p2* in Image 2, are input to compute the *Xp*, *Yp*, and *Zp* coordinates of ground point *P*.






### image matching

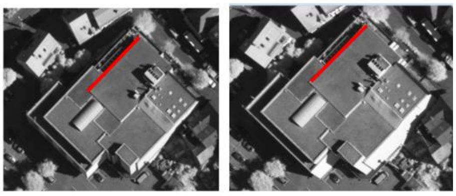
In analogue and analytical photogrammetry, finding the points, it is conjugated (e.g. the coordinates) is achieved by the operator.

In digital photogrammetry, which is known as Digital Photogrammetric Workstation (DPW), the image forms are digital. Therefore, the coordinate is in columns and rows. Finding the coordinate of a point and its conjugate automatically through an image-matching process is achieved as follows.
-First, the point a’ at the left image is specified, and then a template 5x5, the window is located.
-Then, the system will search for the corresponding point on the right image (called conjugate point), then measure the correlation.
-Repeat the process until all the location in the right window is visited,
-The highest correlation is the conjugate point.

Later the ground coordinates can be calculated using the collinearity equation.


The most known methods are:

### 5.1. -Feature-Based Matching



- Features are extracted in both images independently(such as corners and edges).
- The corresponding point in the other image is found as the nearest neighbour in the descriptor space
- High robustness, fast, and needs only coarse approximation.

### 5.2. Area Based Matching (cross-correlation)

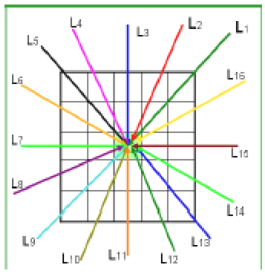
- Points are selected only in the left image (feature point or every n-th pixel).
- The matching partner in the other image is found by correlation.
- Less robust, slow and needs good approximation.

### 5.3. Area Based Matching (Least Squares Matching)

A variant of area-based matching.

- In the other image(s), the template window is not only shifted but also rotated (affine) scaled. Even grey value corrections can be considered to minimize the grey value differences.
- Formulated as an adjustment problem; it allows for the highest possible accuracy

### 5.4. Semi-Global Matching



- Computes conjugate points along multiple conjugate lines hierarchically by using mutual information instead of intensity value differences as a dissimilarity measure.
- It is specified to provide higher quality DSM results than LSM
- Each matching relation induces a matching cost. The sum of all costs defines the global matching cost, which is assumed to be minimal for optimal pixel correspondences.

**Example(area based matching )cross correlation:**

The candidate array A is an ideal template for a fiducial cross, and the following search array S is a portion of a digital image containing a fiducial cross. Compute the position of the fiducial within the search array by correlation.

$$A=\begin{bmatrix}0&0&50&0&0\\0&0&50&0&0\\50&50&50&50&50\\0&0&50&0&0\\0&0&50&0&0\end{bmatrix}\quad S=\begin{bmatrix}41&43&43&49&60&43&41&40&44\\43&44&45&50&64&45&43&43&45\\42&43&44&48&63&49&45&42&42\\42&45&47&50&65&45&45&41&41\\59&62&62&61&69&64&62&63&60\\50&48&48&51&68&55&50&54&53\\42&41&44&48&63&42&47&47&45\\42&44&42&45&62&44&44&45&43\\42&43&44&48&60&47&44&38&35\end{bmatrix}$$

**Solution:**

The Correlation coefficient at the first window position ( with the upper left element of a 5x5 subarray at the 1,1 position of the search array) will be calculated as an example.

1. Extract subarray B from the search array at postion1,1

$$B = \begin{bmatrix} 41 & 43 & 43 & 49 & 60 \\ 43 & 44 & 45 & 50 & 64 \\ 42 & 43 & 44 & 48 & 63 \\ 42 & 45 & 47 & 50 & 65 \\ 59 & 62 & 62 & 64 & 69 \end{bmatrix}$$

2. Compute the average digital number for subarrays A and B.

$$\bar{A} = \frac{0+0+50+\cdots.+50+0+0}{25} = 18$$

$$\bar{B} = \frac{41+43+43+\cdots..+62+64+69}{25} = 51.48$$

3. Compute the summation terms for the correlation coefficient.

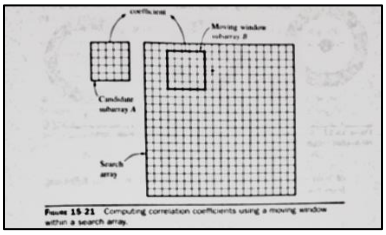
$\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(A_{ij}-\bar{A}\right)\left(B_{ij}-\bar{B}\right)\right] = (0-18)(41-51.48)+(0-18)(43-51.48)+(50-18)(43-51.48)+ \cdots.+(50-18)$(62-51.48)+(0-18)(64-51.48)+(0-18)(69-51.48)=-1316

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\left(A_{ij}-\bar{A}\right)^2 = (0-18)^2+(0-18)^2+(50-18)^2+\cdots.+(50-18)^2+(0-18)^2+(0-18)^2 = 14400$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\left(B_{ij}-\bar{B}\right)^2 = (41-51.48)^2+(43-51.48)^2+(43-51.48)^2+\cdots.+(62-51.48)^2+(64-51.48)^2 + (69-51.48)^2 = 2102.24$$

4. Compute the correlation coefficient

$$c_{11} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(A_{ij}-\bar{A}\right)\left(B_{ij}-\bar{B}\right)\right]}{\sqrt{\left[\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(A_{ij}-\bar{A}\right)^2\right]\right]\left[\sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(B_{ij}-\bar{B}\right)^2\right]\right]}} = \frac{-1316}{\sqrt{2102.24*14400}} = -0.24$$




5. Compute the remaining coefficients in the same manner

$$B = \begin{bmatrix} -0.24 & -0.09 & 0.35 & -0.19 & -0.19 \\ -0.24 & -0.16 & 0.32 & -0.21 & -0.32 \\ 0.25 & 0.37 & 0.94 & 0.29 & 0.27 \\ -0.08 & 0.02 & 0.50 & -0.06 & 0.03 \\ -0.28 & -0.23 & 0.27 & -0.18 & -0.22 \end{bmatrix}$$

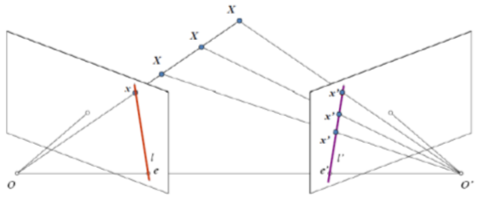
6. Select the maximum correlation coefficient, which is 0.94, and occurs at row 3 , column 3 of the C array.

## 6. Epipolar geometry

The above technique, image matching, is an intensive and time-consuming task. Therefore, it is preferred to constrain the search area through epipolar geometry.

Epipolar geometry aids in constraining the search region to be along a single line.

If the relative orientation is known for a given stereo pair, the coplanarity condition is established and thus can be used to define **epipolar lines.**



## 7. DSM sampling

In order to construct a comprehensive and usable DSM, it is necessary to establish the topological relationship between the data elements as well as the interpolation model.

It is difficult to measure all the points on the surface, such as the earth. Consequently, a sampling method must be used to extract representative points, which are used to build the surface model.

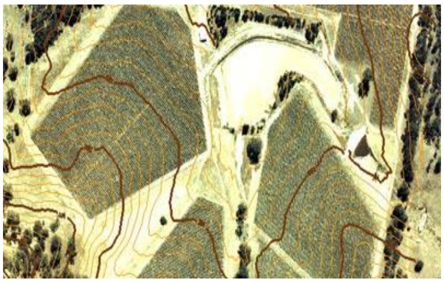
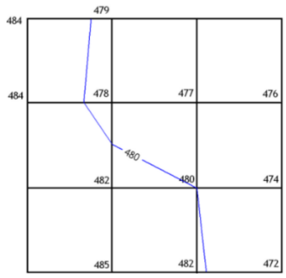
These points should be specified to be:

1) Accurately represent the surface
2) Be suitable for efficient data collection
3) Minimize data storage requirements,
4) Maximize data handling efficiency
5) Be suitable for surface analysis.

Three methods are used to represent surfaces in digital form:

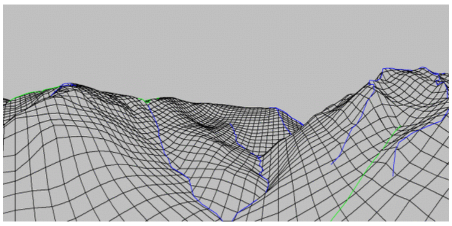
### 7.1. Contours

- Contour or isolines is the line of constant elevation at a specified interval.
- Contour accuracy depends upon whether the isoline has been generated from primary or derived data.

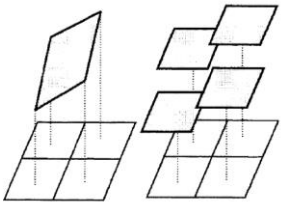



### 7.2. GRID

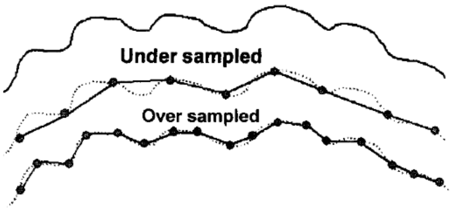
- Grids are a matrix structure that implicitly records the topological relationship between data points.



- A lattice is the surface interpolation of a grid represented by equally spaced sample points referenced to a common origin and a constant sampling distance in the x and y direction, with a z-value assigned to each point.



- The point density of regular grids cannot be adapted to the complexity of the relief. Thus, peaks and pits can be missed. So that an excessive number of data points are required to represent the terrain to the required level of accuracy, as shown in the figure:




### 7.3. Triangulated Irregular Network (TIN)

- It is a significant model that is an alternative to the regular raster-grid- model. It is based on building a surface based on a set of irregularly distributed points.

- It is useful when taking more points at the rough areas and fewer points at the area of smooth terrain. Therefore is considered more efficient in representing ground than Grid models.