SE 422 Advanced Photogrammetry

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Operations of Photogrammetry

Content

- Main functions of Photogrammetry
  - Resection
  - Intersection
  - Triangulation
- Self-Ray Backprojection
- Relative Orientation
- Absolute Orientation

Resection, Intersection and Triangulation

- The basic functions or operations in photogrammetry are:

1) Resection
2) Intersection
3) Triangulation or sometimes referred to as Block Adjustment

- We will define each operation and discuss their mathematical model and the unknows.

Resection

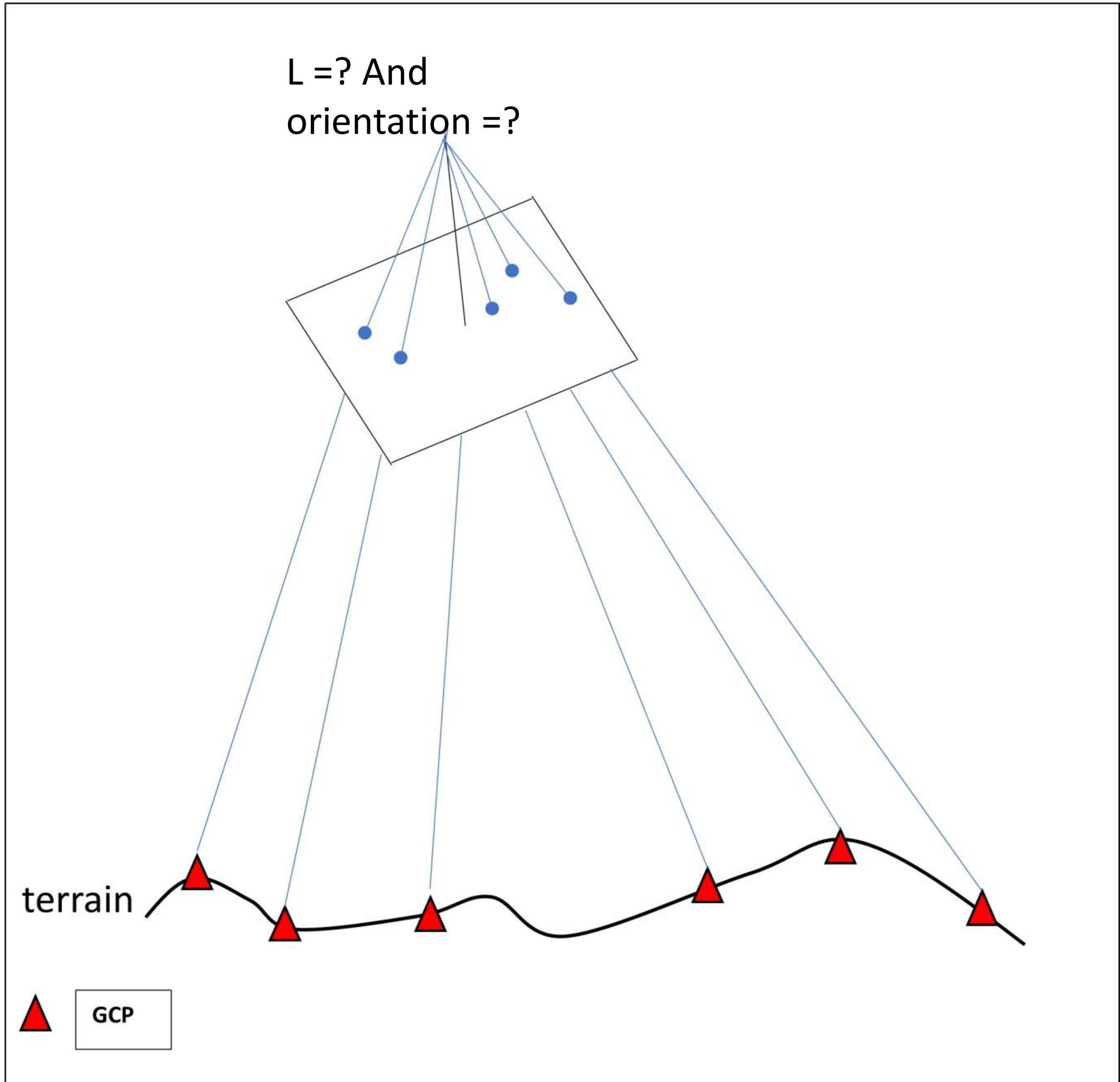
- Resection is defined as the "determination of the position and orientation of an image in space" *E. Mikhail, J. Bethel, and C. McGlone*

- In the standard resection case: the parameters include the object space coordinates of the perspective center (XL, YL, ZL) and three orientation angles $(\omega, \phi, and\ \kappa)$

- Resection is also can be used to determine the position and orientation indirectly. For instance, the coefficients of a set of polynomials that describe the position and orientation of a time-varying sensor w.r.t time (using Direct Linear Transform DLT)

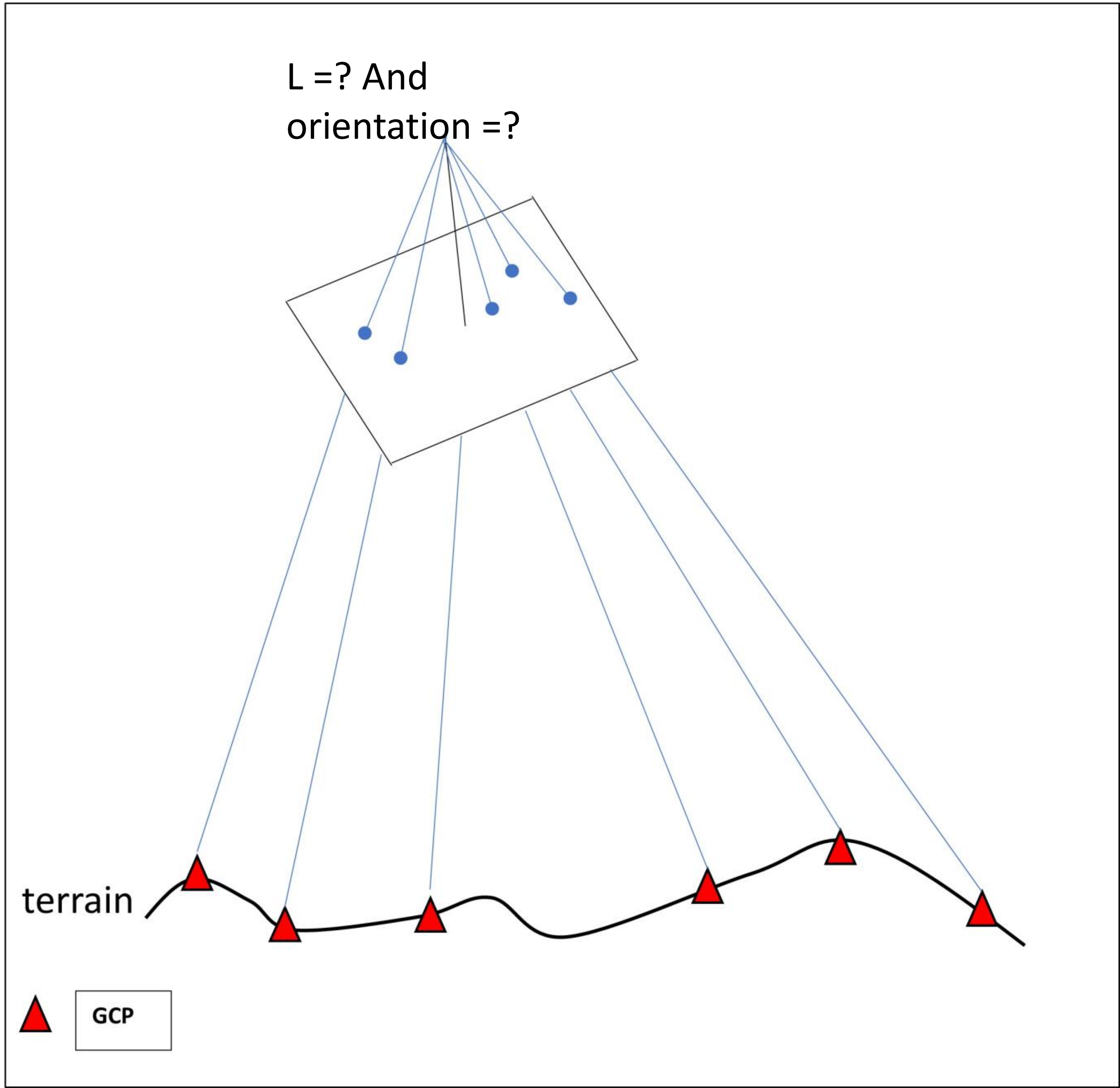
Resection

- As we have seen from the previous slide, the parameters we are trying to estimate in this type of operation are: XL, YL, ZL and the orientation angles (ω, ϕ, and κ)
- From the figure, GCPs are known, their corresponding image coordinates are measured, and the unknown in that problem is the Exposure Station Location and Orientation



Resection

- From that, the minimum number of GCPs needed to solve for the EOPs is three full noncollinear points (what do we mean by full point and noncollinear points?)
- There are many different formulations of the resection problem



Resection

- Closed-form solution and Iterative solution
- Closed-form solutions are usually faster due to their lower computational requirements.
- Another advantage of the closed-form solution is that it does not require initial approximations for the EOPs
- The closed-form solution is popularly used in computer vision applications that run without operator input or editing
- The iterative solution resection has better accuracy over the closed-form because it uses the redundancy of the observations and least-squares techniques

Resection

- The solution can be unstable if the control points and the perspective center all lie on or close to a cylinder surface even though the control points are available and sufficient
- We can use the geometric information within the scene side by side with the collinearity equation if we know for instance that some points are lying on straight lines or circles with known orientation

Resection

- Using the minimum number of points will yield a unique solution:

$$6\ unknowns$$
$$3\ full\ noncollinear\ GCPs$$
$$6\ observations\ (three\ image\ points\ corresponding\ to\ the\ GCPs)$$
$$2\ collinearity\ equations\ per\ point = 6\ collinearity\ equations$$

- If more observations are added, a least-squares solution can be performed to obtain better results and allow for point measurement editing

- In that case, the collinearity equation must be linearized, and initial approximations must be provided for the parameters

Resection

- We can get initial approximation values from navigational sensors, such as GPS, flight plans, from reference to maps or previously resected images, or from an initial closed-form solution
- Resection as we mentioned previously is one of the most operation of Photogrammetry, but it is rarely used in practice except as a first step to generate the approximations for the Bundle-Block Adjustment (BBA) model

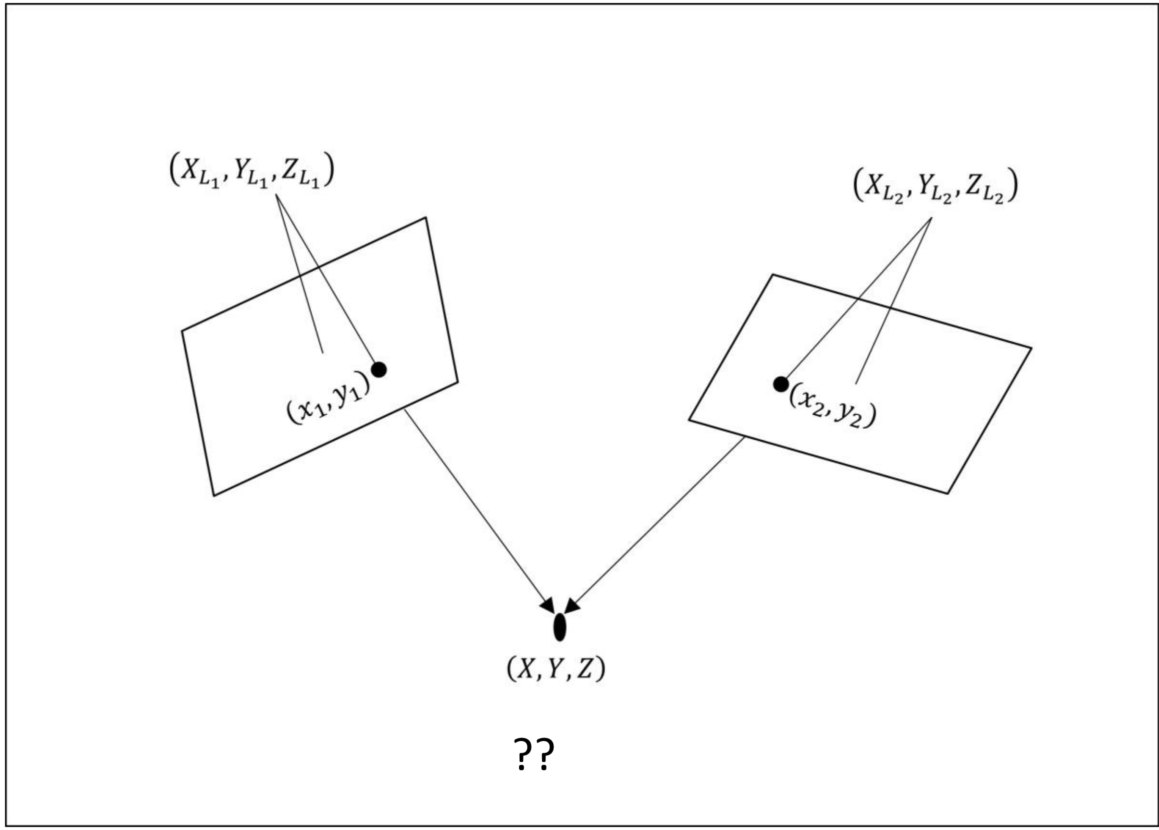
Intersection

- Intersection is defined as “the calculation of the object space coordinates of a point from its coordinates in two or more overlapped images” *E. Mikhail, Bethel, and C. McGlone*

- Again, it uses the collinearity equation as a standard model (application of collinearity)

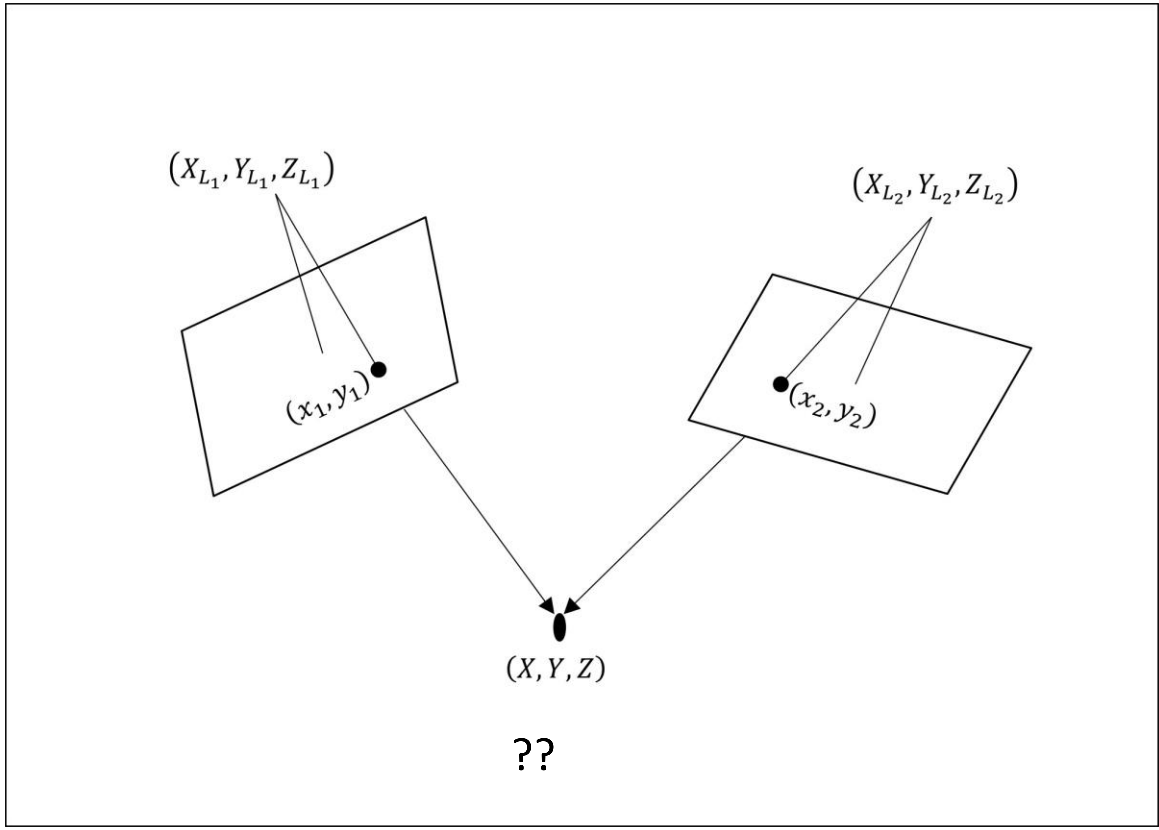
Intersection

- In that model, we have 3 unknowns/point, (X, Y, and Z)
- We know that to get the 3D information of a point, a minimum of two overlapped images is required
- As we have covered in the collinearity equation part, each observed point will generate two equations
- The minimum number of points needed to estimate the unknowns is two points observed in two different photos



Intersection

- Solving for the point object coordinates using the minimum number of points will give a degree of freedom (redundancy) to one
- Adding more images increases the number of degrees of freedom and improves the solution
- The solution will be solved using the least-squares techniques after linearizing the collinearity equation as we have done previously



Intersection

- We can obtain the initial approximated values for the coordinates of the point either by Single-ray backprojection (will discuss later) or by approximate intersection calculations

- As we recall from SE331, performing least-squares adjustment will lead to minimizing the weighted sum of the image residuals squared

DO NOT FORGET, THE MOST FORMATION OF COLLINEARITY EQUATION USED IN INTERSECTION AND RESECTION PROBLEMS IS:

$$x'' = -f\,\frac{\left(m_{11}(X - X_L) + m_{12}(Y - Y_L) + m_{13}(Z - Z_L)\right)}{\left(m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)\right)}$$

$$y'' = -f\,\frac{\left(m_{21}(X - X_L) + m_{22}(Y - Y_L) + m_{23}(Z - Z_L)\right)}{\left(m_{31}(X - X_L) + m_{32}(Y - Y_L) + m_{33}(Z - Z_L)\right)}$$

Next lecture:

- Lab-4: We will do an example of a Resection Problem using real data. (NO MORNING CLASS ON TUESDAY)
- HW-5, we will use real data to recover the position of an image using GCPs (Resection Problem) (the due date for this HW is 13/2/2023).
  - The main functions will be provided (getting the observations through an image, making the necessary corrections (refinements), and the condition equation and its partial derivatives).
  - You need to figure out how to build the model and make the LS iterative model.
- Covering the last part of the operations of Photogrammetry (Sunday, 5/2/2023)
- Quiz-6: Covering this week's lecture. (Sunday, 5/2/2023)

Block Triangulation

- In the triangulation operation (function), the images EOPs and the coordinates of the points are calculated simultaneously
- Block Triangulation has been a major factor in improving the economic feasibility of photogrammetric mapping
- Without Triangulation, every stereo model would require two horizontal and three vertical control points plus checkpoints, which requires expensive ground surveys.
- There are many ways to make the triangulation, such as Polynomial strips, Block adjustment by independent models, and Bundle Block Adjustment
- The function that is mainly used these days is the Bundle-Block Adjustment

Bundle Block Adjustment (BBA)

- BBA is the most accurate and flexible method of triangulation currently in use
- The addition of self-calibration parameters corrects for remaining systematic errors and increases the overall accuracy
- The collinearity and coplanarity equations can be incorporated together to add information, which increases the precision

Bundle Block Adjustment

- This model solves all the unknown parameters
- In this model, we need initial values for EOPs and 3D object points coordinates.
- IOPs are either known from previous experiments or obtained in the lab.
- Also, IOPs can be assumed as unknown and solved for them.
- The process of solving for the IOPs during the BBA estimation is called the Camera Self-Calibration model
- In that model, at every block of photos added to the BBA model, IOPs will be assumed fixed.

Bundle Block Adjustment

- After adding a block of photos (defined by the operator), these IOPs will be set free, and they will be assumed unknown to solve for them.
- After finding their estimated value, these values will be used and fixed again.
- These previous steps will be repeated each time a block of photos is added to the BBA model.

Single-Ray Backprojection

- This method is used to determine the object space information of a point appearing in one image
- Since the 3D information about the world is lost when it is projected into a 2D image, we must have additional information before we can backproject the ray into the world
- The simplest way to do that is by backprojection to a given coordinate plane
- For example, projecting to a fixed elevation (Z fixed).
- The solution for X and Y is straightforward using the inverse of the collinearity equation
- Using the backprojection of the image ray to a DEM is very complicated

Relative Orientation

- If we have two images taken from different viewpoints, we can create a Stereo-Model that can be used to obtain a three-dimensional impression of the scene
- The projected rays through conjugate points must intersect in space
- This will reestablish the original epipolar geometry of the pair of the images
- This procedure is known as *Relative Orientation*

Relative Orientation

- RO parameters can be performed manually by adjusting the orientation elements of an analog stereo plotter (SE321)
- Or, analytically by measuring corresponding image points and calculating the orientation parameters
- RO involves the determination of 12 parameters with the degrees of freedom of 5
- By using the Absolute Orientation, which relates the model space to the object space, the 7-parameter can be determined
- This leaves 5 parameters to be determined along the RO

Relative Orientation

- There are several ways to estimate these 5 parameters
- One way to do that is by using *Dependent RO*
- In this approach, all the parameters of one image, along with one position parameter in the second image, can be fixed
- Remaining parameters of the second image are adjusted, as shown in the figure
- This leaves the two position parameters and three orientation parameters of the second image to be determined

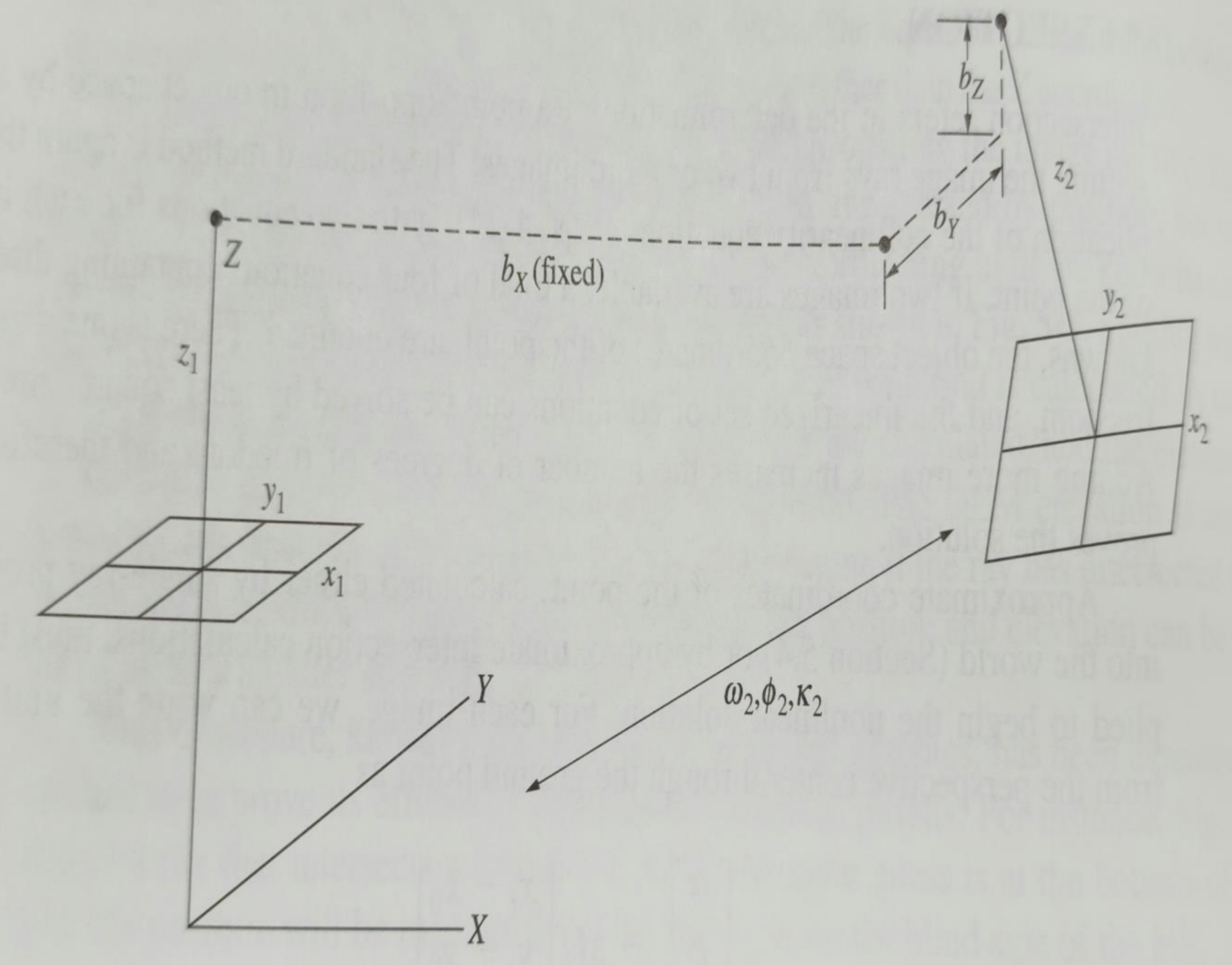


Figure 5-5 Dependent relative orientation.

Relative Orientation

- RO can be performed with more than two images
- This can be done in a sequential procedure
- Once the first pair of images is relatively oriented, each successive image is oriented to its preceding image

Absolute Orientation

- This step is done before a relatively oriented stereo model is used for mapping
- It establishes the relationship between the model space and object space coordinate systems
- This approach has 7 parameters, which are:
    - A uniform scale
    - 3 rotations
    - 3 translations

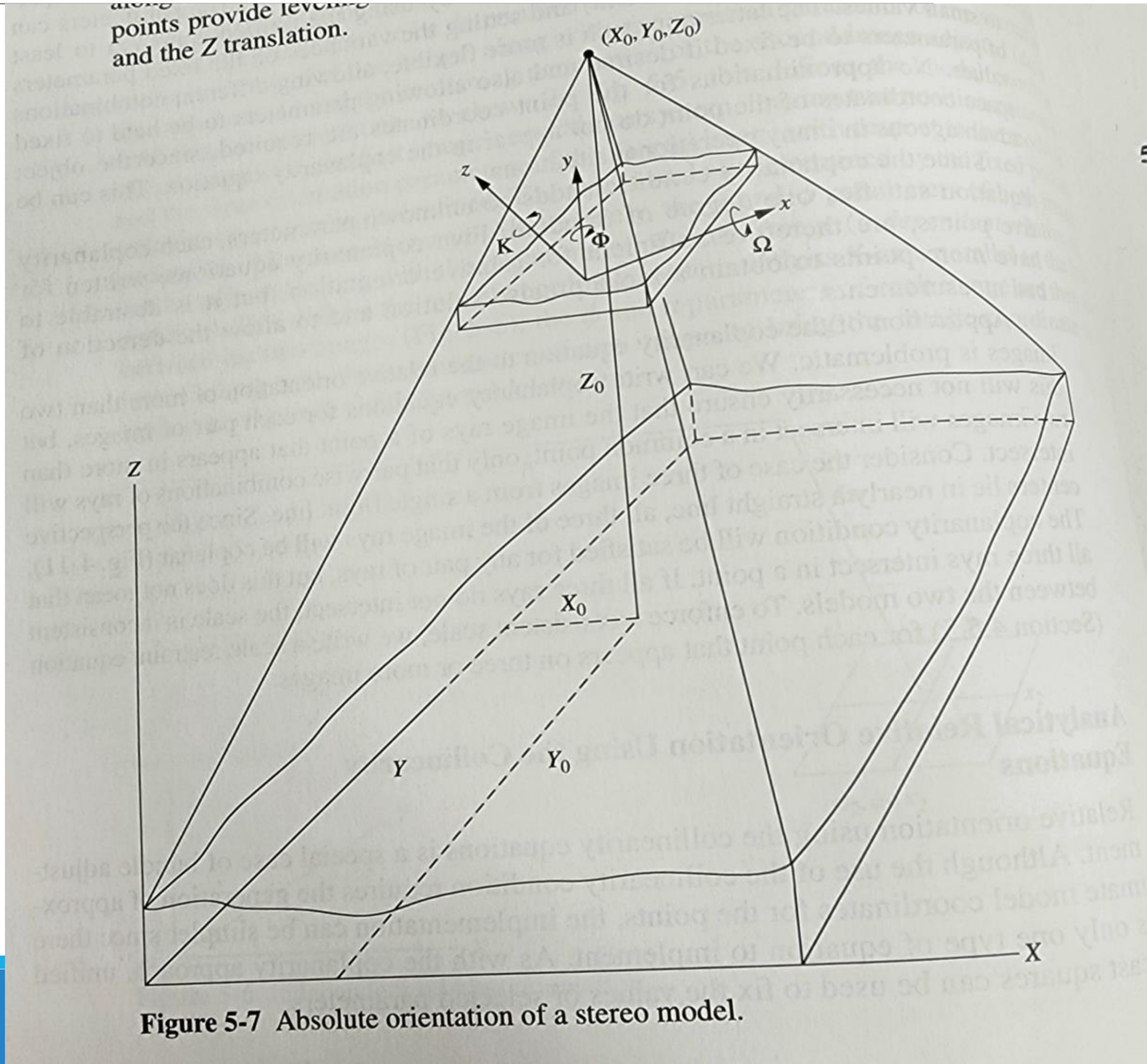


Figure 5-7 Absolute orientation of a stereo model.

Absolute Orientation

- When working on an analog stereo plotter, AO is performed empirically
- To estimate the parameters:
  - Two horizontal control points in the model will provide: the scale, the translations around the X and Y axes, and the rotation around the Z-axis (Κ)
  - Three elevation control points will provide leveling information (the rotations around X and Y axes (Ω and Φ) and the Z translation

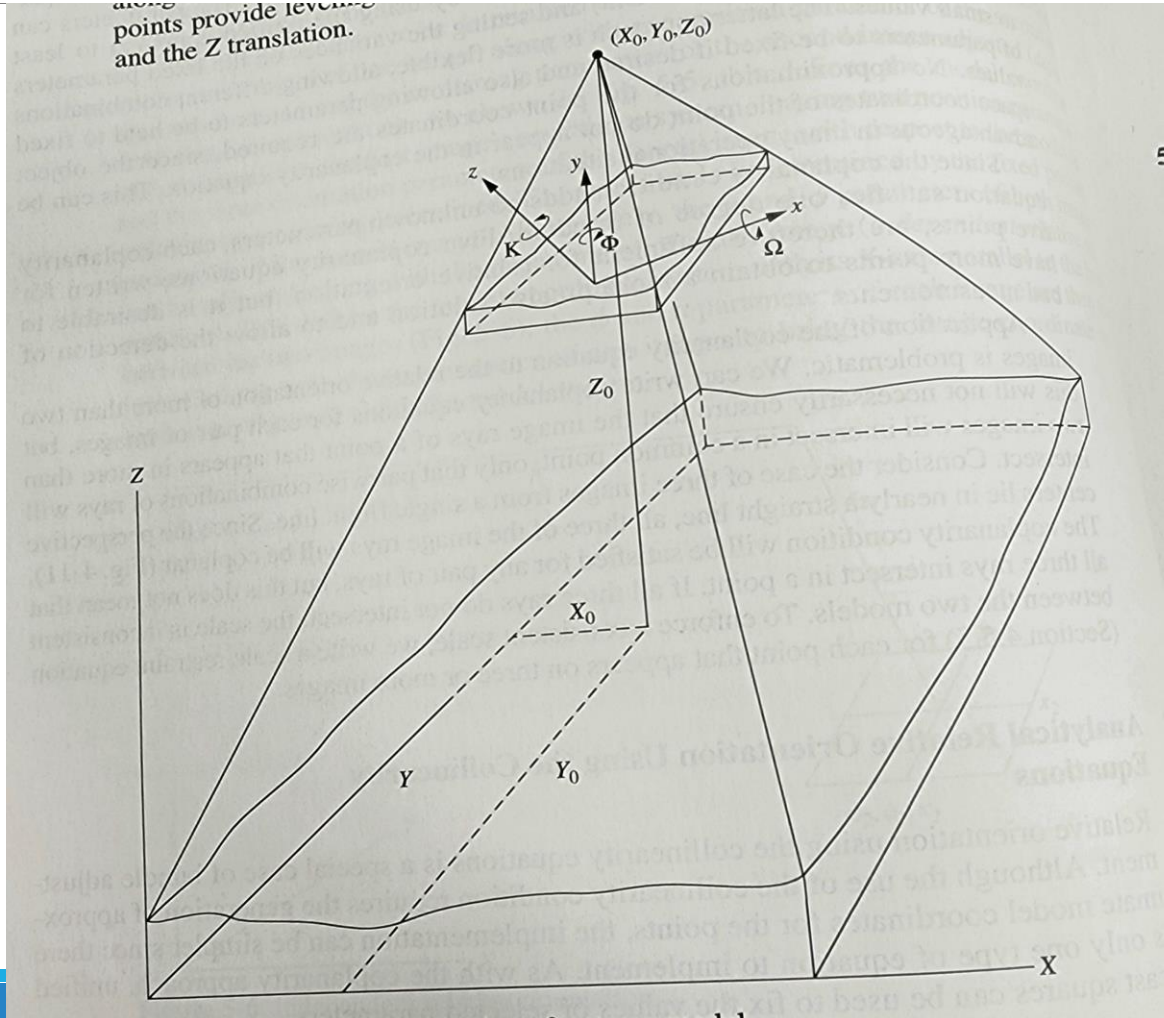


Figure 5-7 Absolute orientation of a stereo model.

Absolute Orientation

- When performing the AO analytically, the model is based on the 3D similarity transform (which we described as the 7-parameter model before)

$$Y = \mu MX + T$$

Where Y is the vector of known world coordinates, M is the rotation matrix, X is the vector of the model coordinates, and T is the translation vector

- This model will be a set of three scalar equations per point

- Since the solution is nonlinear, approximations must be generated before the solution can be proceed
  - The scale can be estimated by calculating the ratio of the distances between a pair of points in the model space and the object space

$(recall\ for\ the\ scale\ equation\ we\ introduced\ before\ scale = \frac{d_{xyz}}{d_{XYZ}})$, where d_{xyz} is the distance between two points in (xyz) coordinates system and d_{XYZ} is the distance between the same two points in (XYZ) coordinates system

Absolute Orientation

- For models constructed from vertical photos: the tilt can be approximated as zero
- The rotation around the Z-axis can be determined by calculating the azimuth between two points in both model space and object space coordinate systems
  - Then the approximation is set to be the object space azimuth minus the model space azimuth

- The translations can be calculated by applying the approximate scale and rotation matrix to a point in the model system, then subtracting the transformed coordinates from its object space coordinates
- Another way to compute the approximated translations (tx, ty, and tz) is by using the mean between each translation coordinate components
  - For example: $tx_{approximated} = \frac{1}{n}\sum X_i - \frac{1}{n}\sum x_i$

Next Lecture:

- Sunday ➔ No Class
- Tuesday ➔ No morning class, but we will meet during the lab time