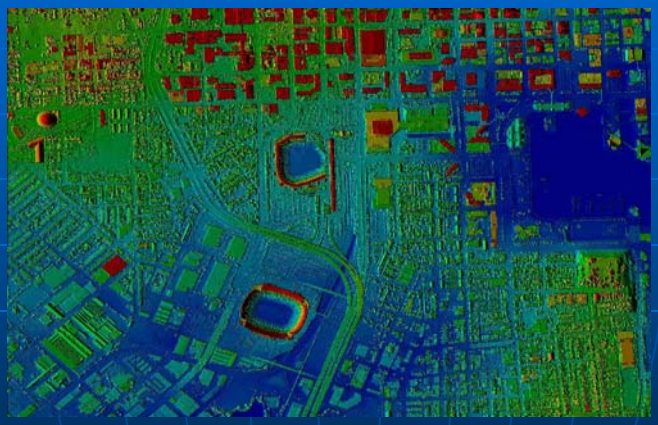
Photogrammetry Review



Neil King
King and Associates

Introduction

- Testing is an art
  - Read the question
  - Re-Read The question
  - What is being asked
  - Answer what is being asked
  - Be in the know
  - Exercise the art of Visualization
  - Accept the Suggestion of Passing

Introduction

- Photogrammetry
  - Photos – *light*
  - Gramma – *drawing*
  - Metron – *measure*
- Basic Definition

  "The art and science of obtaining reliable measurements by means of photographs."

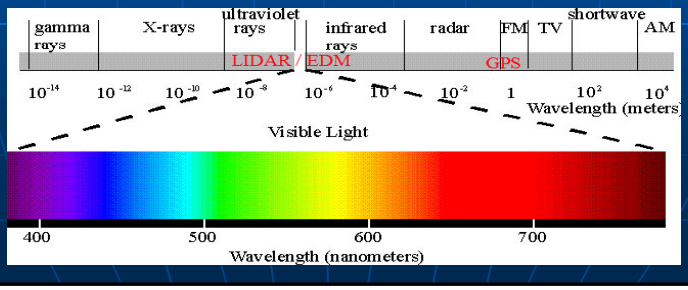
Introduction

- American Society for Photogrammetry and Remote Sensing, ASPRS
  - Refined Definition

    "The art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena."

Introduction

- Electro Magnetic Spectrum
  - Gamma Rays to Radio Waves
  - Invisible to Visible
  - Defines our world as we see it
  - Utilized by Photogrammetric Sensors
  - Unlimited Possibilities



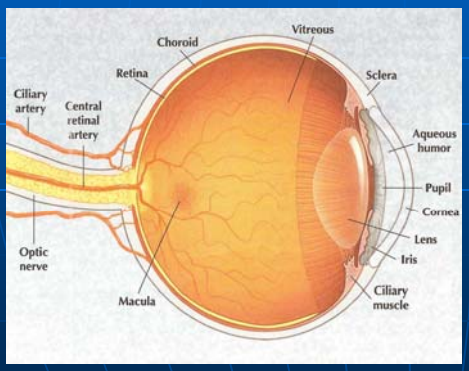
Introduction

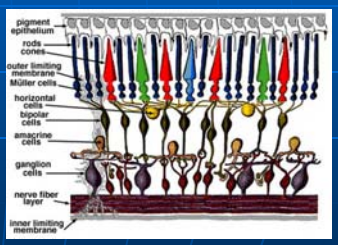
Sensors and the Electro Magnetic Spectrum

- Sensors detect physical information
- Converted to electrical signals
- Translated to angles, distances, reflectance, etc
- Tied to Arbitrary and Local reference frames
- Developed into models
- Decision Analysis
- Geomatics

Introduction

- Human Vision an Amazing Sensor





Introduction

- Photogrammetric Technology

Introduction

- Photogrammetric Future
  - UAV + Sensor Combination & Fusion



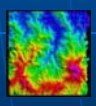
Introduction

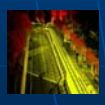
Photogrammetic Range


Aerial Photography


Photogrammetry / Digital Mapping

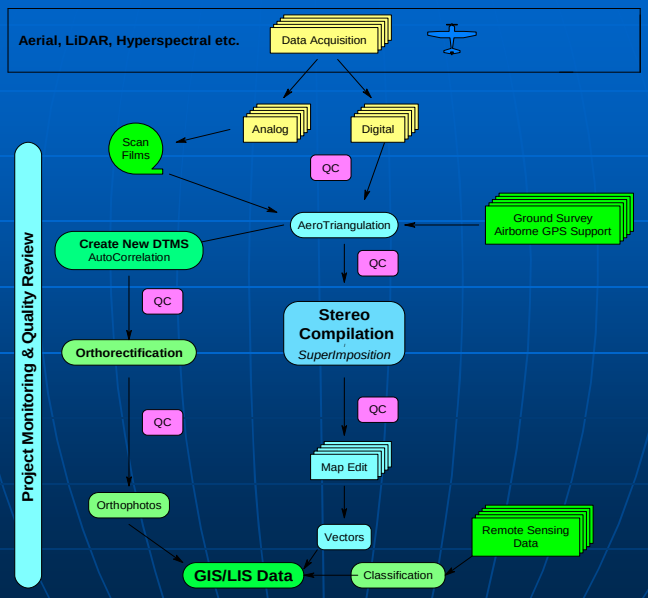

Digital Orthophotography


LiDAR Mapping


Mobile Mapping


Remote Sensing

Photogrammetric Production



Geometric Key Concepts

- Scale — $S = f / H$
- C-Factor — $Cf = H / CI$
- Relief Displacement — $h = d * H / r_2$, $d = r_2 - r_1$
- Scale Choice — Horizontal vs Vertical Requirements
  - $Scale_{map} = Scale_{photo} / Enlargement$
  - $Scale_{map} = f / CI * C\text{-factor}$
- End Lap Gain — $S * L * [(100 - End\ Lap\ \%) / 100]$
- Side Lap Gain — $S * W * [(100 - Side\ Lap\ \%) / 100]$
- Min Number of Models — (Length / End Gain) round up
- Min Photos per flight Line — (Length / End Gain) round up + 1
- Min Number of flight Lines — (Width / Side Lap Gain) round
- Ground Control — Vert = 3+1 Horiz = 2+1
- Target Size — W= ps*0.002, Legs = 12*W

Geometry of Aerial Photographs

- Photogrammetric Photography
  - Frame Metric Cameras
  - Vertical Photography
    - Image Plane Parallel to the Ground, Nearly
    - Optical Axis Perpendicular to the Ground
    - Contains 3D Information
  - Perspective based
    - All Light Rays converge at the lens
    - Weakest measurement along the optical axis
    - Heights require rigid constraints
  - Overlapping Photography
    - Stereoscopic Coverage
    - (end lap, side lap)

Geometry of Aerial Photographs

- Frame Metric Cameras
  - Analog
    - Film Based
    - Standard Frame size 9” by 9”
    - Focal Length 6”,154mm / 12”,305mm
    - Calibration Report (date range)
  - Digital
    - CCD based, Concept of Pixels
    - Variable frame Size 14430,9420 / 13824,7680
    - Variable focal length 100mm / 120mm
    - Calibration Report (date range)

Geometry of Aerial Photographs

- Scale Expression
  - Representative Fraction
    - Ratio
    - One unit = a similar number of same units
    - 1 inches = 100 inches or 1:100
  - Map Or Engineers Scale
    - Ratio
    - One unit = a similar number of different units
    - 1 inch = 100 feet

Geometry of Aerial Photographs

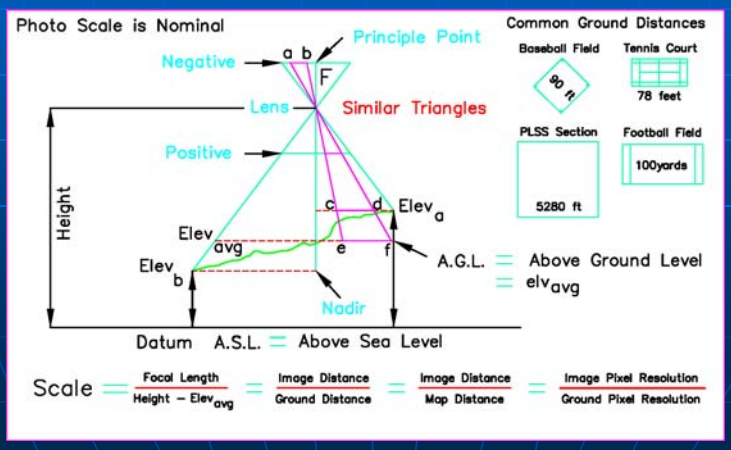
- Scale Small Vs Large
  - Smaller Scales
    - Cover larger areas
    - 1:24,000 or 1 inch = 2,000 ft
  - Larger Scales
    - Cover smaller areas
    - 1:1,200 or 1 inch = 100 ft

Geometry of Aerial Photographs

- Scale Maps vs. Aerial
  - Maps
    - Scale is constant
    - No relief displacement
    - Orthographic or Planimetric Projection
  - Aerial Photos
    - Scale varies
    - Topographical Relief displacement is present
    - Aerial photos have nominal scale
      - Varies with Topographical Relief
    - Perspective Projection

Geometry of Aerial Photographs

- Geometry of Photographic Scale
  - Geometry of Similar triangles



Geometry of Aerial Photographs

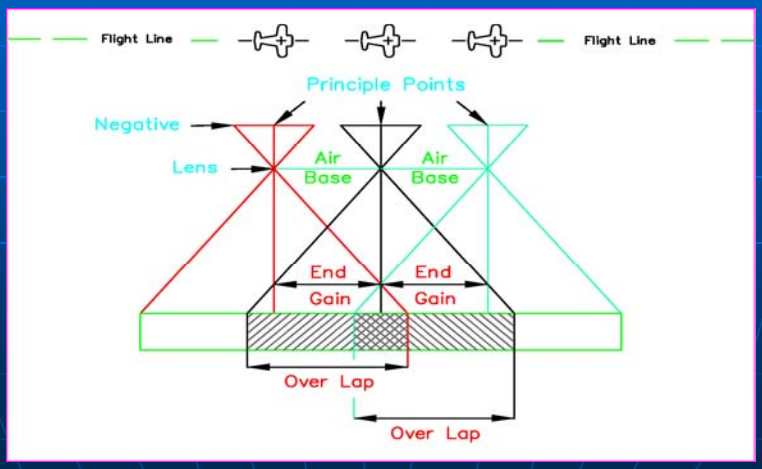
- Photographic Over Lap
  - Forward Over Lap
    - Over Lap between Photographs along the Flight Line
    - Provides Stereoscopic Coverage
    - 3D Viewing and measuring
    - Provides small over lap between alternate photographs for extending control through the Analytical of process AeroTriangulation
  - Side Lap
    - Side lap Between the Flight Lines
    - Allows extending control to successive flight lines through the Analytical process of AeroTriangulation

Geometry of Aerial Photographs

- Photographic Gain
  - End Lap Gain
    - Principle Point to Principle Point
    - Scale * Length * [(100 – End Lap %) / 100]
    - 9 inch Width and 60 % end lap
    - Scale Photo * 3.6 in
  - Side Lap Gain
    - Distance between Flight Lines
    - Scale * Width * [(100 – Side Lap %) / 100]
    - 9 inch Width and 30 % end lap
    - Scale Photo * 6.3 in

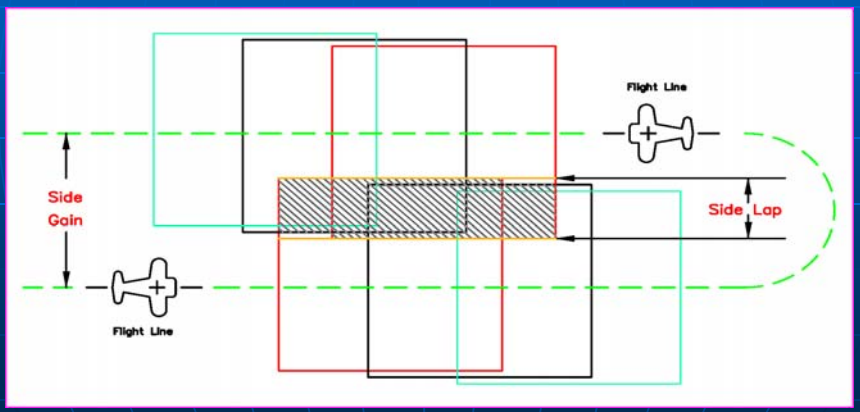
Geometry of Aerial Photographs

- End Lap Gain



Geometry of Aerial Photographs

- Side Lap Gain

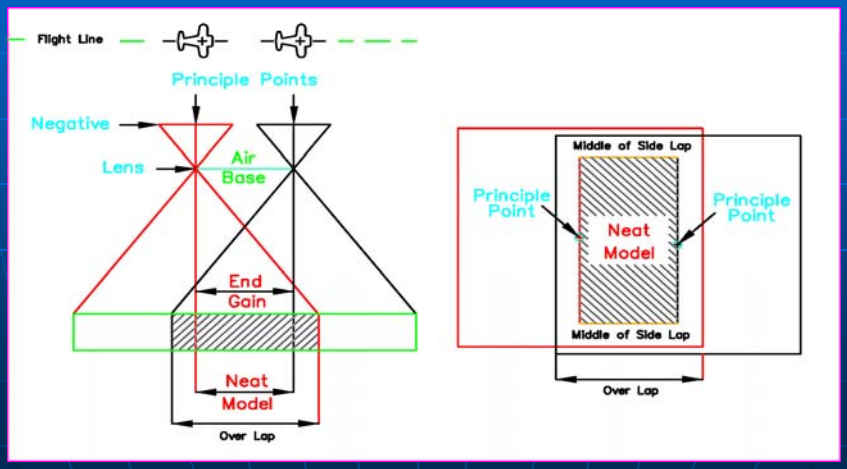


Geometry of Aerial Photographs

- Neat Model
  - The stereoscopic area between adjacent principle points, (Exposure Stations), and extended out sideways in both directions to middle of the side laps
    - If no side laps exist, one can extend to no more then 1" from the extents of the dimension of the Frame on either side

Geometry of Aerial Photographs

- Neat Model

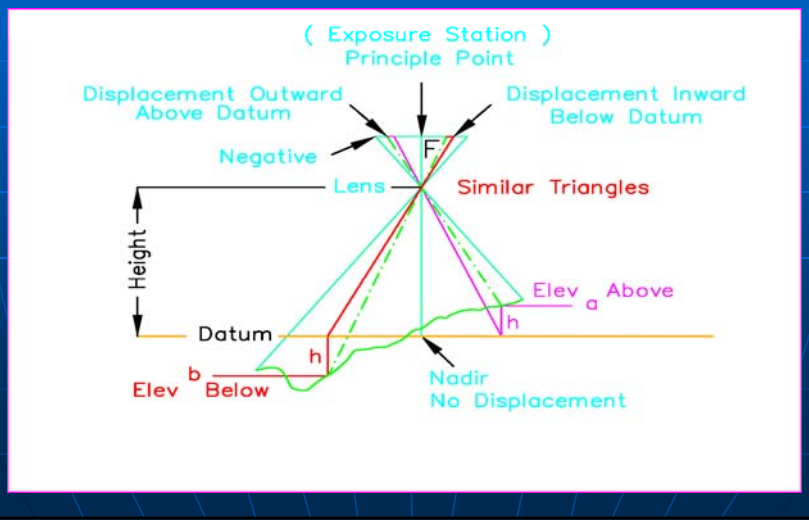


Geometry of Aerial Photographs

- Relief Displacement
  - The radial distance between where an object appears in an image to where it actually appears on the Datum, (ground)
  - Causes
    - Camera Tilt and Earth Curvature – Minor
    - Topographic Terrain Relief or Elevation Differences – Major
      - Displacement is a radial distance outwards for elevations above the Datum
      - Displacement is a radial distance inwards for elevations below the Datum
    - The nadir point on the datum, opposite the principle point, (Exposure Station), is always free of any relief displacement.

Geometry of Aerial Photographs

- Relief Displacement

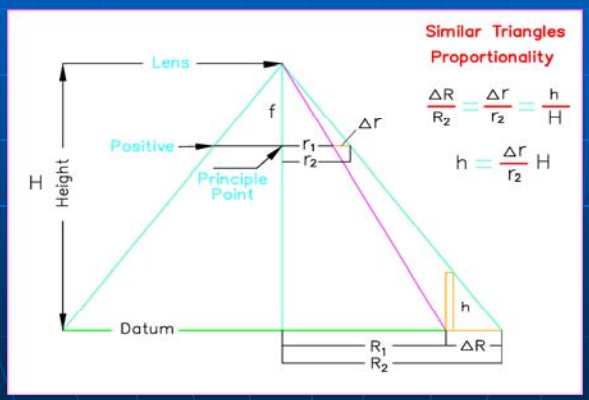


Geometry of Aerial Photographs

- Object Heights and Relief Displacement
  - $h = \Delta r * H / r_2$
    - h = height of object
    - r_1 = radial distance from the principle point to base of an image object
    - r_2 = radial distance from the principle point to top of an image object
    - H = flying height
    - $\Delta r = r_2 - r_1$
  - Proportionality

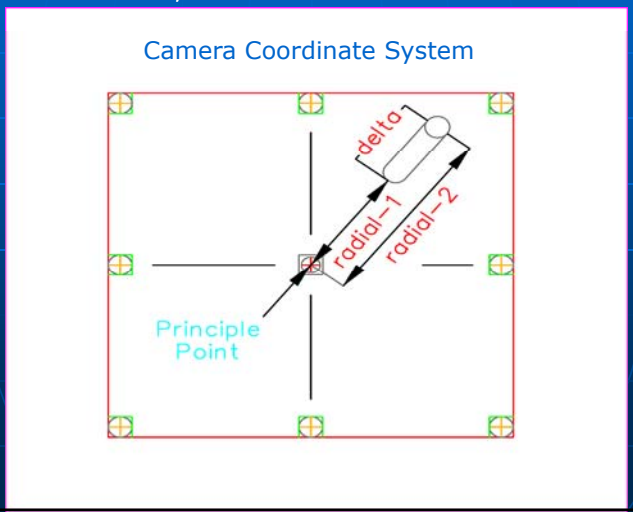
Geometry of Aerial Photographs

- Object Heights and Relief Displacement



Geometry of Aerial Photographs

- Object Heights and Relief Displacement
  - $h = \Delta r * H / r_2$, $\Delta r = r_2 - r_1$ (Proportionality)



Geometry of Aerial Photographs

- C-factor
  - Is an empirical value that defines the ability to accurately measure the vertical component in a stereo model using a given type of photogrammetric instrumentation.
  - Vertical measurements depend not only on the photogrammetric instrumentation, but also upon the nature of the terrain, the camera and its calibration, the resolution quality of the photography, the density and accuracy of the ground control

Geometry of Aerial Photographs

- C-Factor is Based Upon
  - Photographic Geometry
    - Focal Length of the Frame Camera (f)
    - Flying Height (H)
    - Air Base (b)
      - Distance between exposures
    - Key: Air Base to Flying Height Ratio (b / H)
  - Image Measurement Accuracy at photo scale
    - The ability to "discriminate increments of error in elevation"
    - The measurement of Parallax

Geometry of Aerial Photographs

- C-factor Mathematical Formulation

[Light et. al., 1999]

$$C - factor = \frac{H}{CI} = 0.21 \frac{b}{H} \frac{f}{\sigma_i}$$

σ_i = image measurement accuracy (Parallax)
H = flying height above ground
f = the focal Length
b = Air base, distant between successive exposure stations
CI= Contour Interval

Based on NMAS

Flying Height = Contour Interval * C-factor

Photogrammetric Plotters

- StereoPlotters
  - Softcopy
    - Fifth Generation
    - All digital environment on computer
    - C-Factor=2000, resolution = 3-5 µms, Enlargement 7x
  - Analytical
    - Fourth Generation
    - Optical and Computer environment
    - Diapositives
    - C-Factor=2000, resolution = 3-5 µms, Enlargement 7x
  - Analog
    - Third Generation
    - Optical, Scribing and Computer environment
    - Diapositives
    - C-Factor=1600, resolution = 10-15 µms, Enlargement 6x

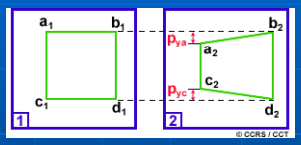
Photogrammetric Plotters

- Stereoscopic Parallax
  - The displacement of an object caused by a change in the point of observation is called parallax.
  - Stereoscopic parallax is created by overlapping aerial photographs of the same object from different points of observation.
  - Overlapping aerial photos are referred to as stereopairs and can be used to measure object height.
  - Stereopairs are utilized to interpret objects, locate objects and determine object heights. They contain Y and X Parallax.

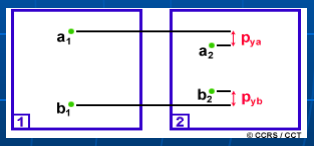
Photogrammetric Plotters

- Stereoscopic Y Parallax (Relative Orientation)
  - Difference in perpendicular distances between two image of a point from the vertical

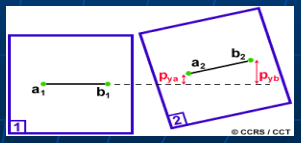
Y-Parallax due to tilt



Y-Parallax due to variation of heights

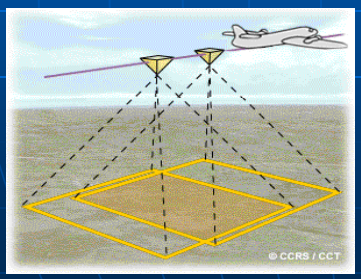


Y-Parallax due to miss-alignment



Photogrammetric Plotters

- Stereoscopic X Parallax (measurements)
  - The Difference in the position of observation of a point as seen in two over lapping photographs, or stereopair



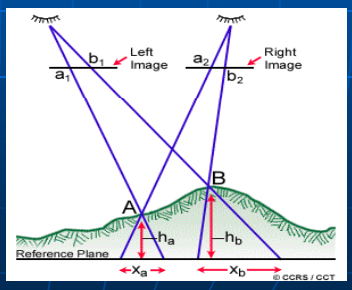


Photo Scale Selection

- Horizontal Requirements
  - Photographic Enlargement Factors
  - Stereoplotter based
  - Scale $_{map}$ = Scale $_{photo}$ / Enlargement Factor
- Vertical Requirements
  - Specified by Contour Interval
  - Use C-factor to find Flying Height
  - Scale $_{map}$ =
    focal Length / Contour Interval * C-factor
- Select the larger of the two derived scales

Models and Flight Lines

- Min Number of Models
  - (Project Length / End Lap Gain) rounded up
- Min Photos per flight Line
  - (Project Length / End Lap Gain) rounded up + 1 photo
- Min Number of flight Lines
  - (Project Width / Side Lap Gain) rounded up

Ground control

- Vertical - Leveling the model
  - Minimum of 3 Vertical points
  - 1 more as a check (Redundancy)
- Horizontal - Scaling the model
  - Minimum of Horizontal 2 points
  - 1 more as a check (Redundancy)
- Minimum to Control a Model
  - 3 points vertical and Horizontal
  - 1 more as a check (Redundancy)

Ground Control

- A Single Model In Practice
  - 4 points vertical and Horizontal
    - At or near the corners
  - 1 as a check in the middle
- For Blocks In General
  - 1 vertical every 2 models edges
  - 1 Horizontial every 4 models edges
  - Supplamental Vertical on the interior

OrthoPhotos

- Image that is corrected for
  - Camera Tilt & Terrain Relief (Orthographic ?)
- Digital Image
  - Requires a digital Image, interior and exterior orientation parameters and a digital elevation surface
  - Rectification
    - The process of removing camera tilt and terrain relief.
    - The process of mathematically re-sampling the input image to the digital elevation surface
    - The process of creating an orthographic projection of the image based upon the digital elevation surface
    - The process of georeferencing

OrthoPhotos

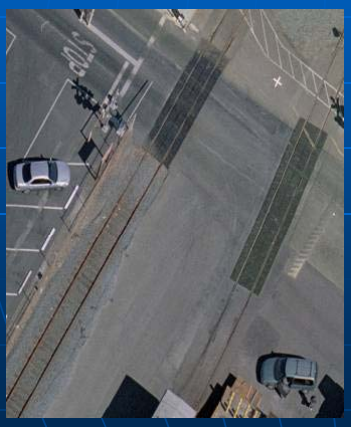
- Digital Image
  - Rectangular file of rows and column
    - Composed of DN values or Grey scale values, pixels
    - Origin most commonly is the Upper left hand corner
    - Pixels have spatial resolution
      - Native resolution or scan resolution (a x b)
      - Ground resolution (A_g x B_g)
      - Scale = image distance / ground distance

OrthoPhotos

- Digital Images
  - Pixels have radiometric resolution
    - The number of bits (binary digits) used to record the illumination level of a pixel
    - 8-bit data = 256 density levels
    - 16-bit data = 65,536 density levels
  - Pixels have Spectral resolution
    - The range of distinguishable EMR wavelengths
    - Black and white
    - Red, Green, Blue
    - Infrared

OrthoPhotos

- Digital Image
  - Pixel Resolution

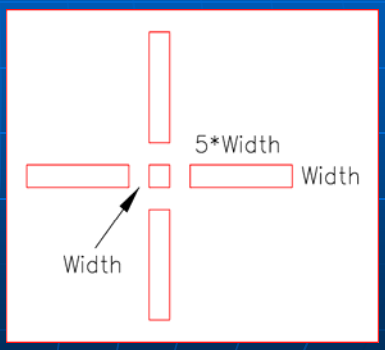


OrthoPhotos

- Digital Image
  - Georeferencing
    - A geographic reference frame
    - World files tfw, jpw, bpw, etc
    - Affine Transformation
      - Line 1: *A*: x component of the pixel width (x-scale)
      - Line 2: *D*: y component of the pixel width (y-skew)
      - Line 3: *B*: x component of the pixel height (x-skew)
      - Line 4: *E*: y component of the pixel height (y-scale), almost always negative
      - Line 5: *C*: *x*-coordinate center of the upper left pixel
      - Line 6: *F*: *y*-coordinate center of the upper left pixel
    - Geotiffs – more information

Aerial Target Size

- Target Size
  - Tied to photo scale
  - Traditionally
    - Width of the Target Legs
      - W = Photo scale * 0.002
    - Length of the Target Legs
      - 5 * W

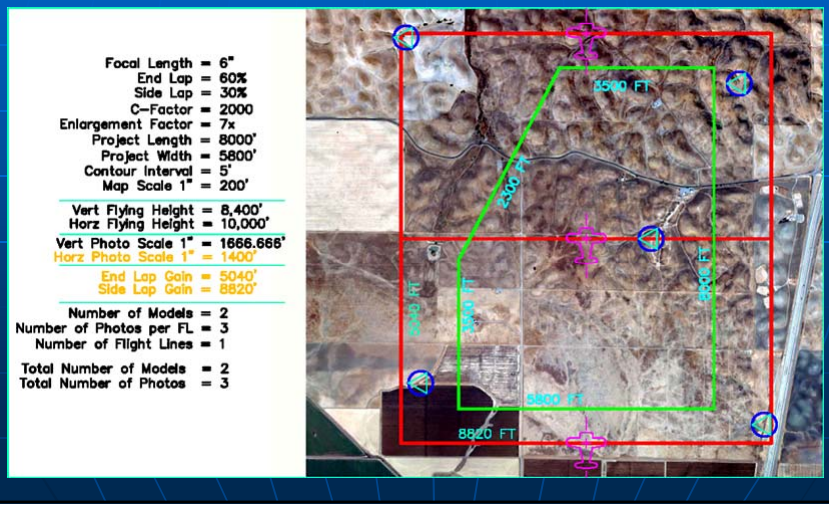


Review

- Scale — $S = f / H$
- C-Factor — $Cf = H / CI$
- Relief Displacement — $h = d * H / r_2$, $d = r_2 - r_1$
- Scale Choice — Horizontal vs Vertical Requirements
  - $Scale_{map} = Scale_{photo} / Enlargement$
  - $Scale_{map} = f / CI * C\text{-factor}$
- End Lap Gain — $S * L * [(100 - End\ Lap\ \%) / 100]$
- Side Lap Gain — $S * W * [(100 - Side\ Lap\ \%) / 100]$
- Min Number of Models — (Length / End Gain) round up
- Min Photos per flight Line — (Length / End Gain) round up + 1
- Min Number of flight Lines — (Width / Side Lap Gain) round up
- Ground Control — Vert = 3+1, Horiz = 2+1, MDL = 3 + 1
- Target Size — W= ps*0.002, Legs = 12*W

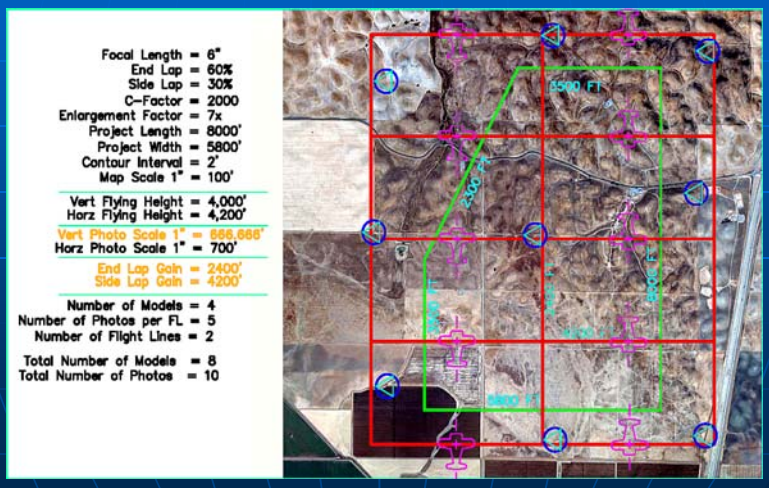
Photogrammetric Projects

- 200 Scale Mapping



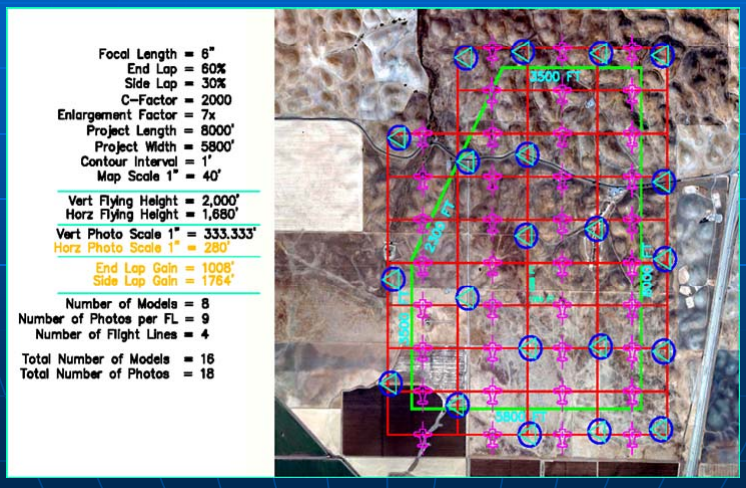
Photogrammetric Projects

- 100 Scale Mapping



Photogrammetric Projects

- 40 Scale Mapping



Reliability of Measurements

- Precision
  - Conformity of repeated measurements
  - Random Probability Distribution with a mean of μ and some random variation σ
  - High Precision
    - Narrow distribution with know quantities
  - Low Precision
    - Wide distribution with know quantities
  - Standard Deviation σ (same quantities)

$$v = x - \bar{x} \qquad \sigma_s = \sqrt{\frac{\Sigma v^2}{n-1}} \qquad \bar{x} \pm \sigma$$

Reliability of Measurements

- Accuracy
  - Conformity with True Values
  - What one would expected the spread to be if the measurements are repeated
  - Standard Error of the Mean
    - Confidence limits for the true mean
    - How many measurements one should make

$$\sigma_m = \frac{\sigma_s}{\sqrt{n}} = \sqrt{\frac{\Sigma v^2}{n(n-1)}}$$

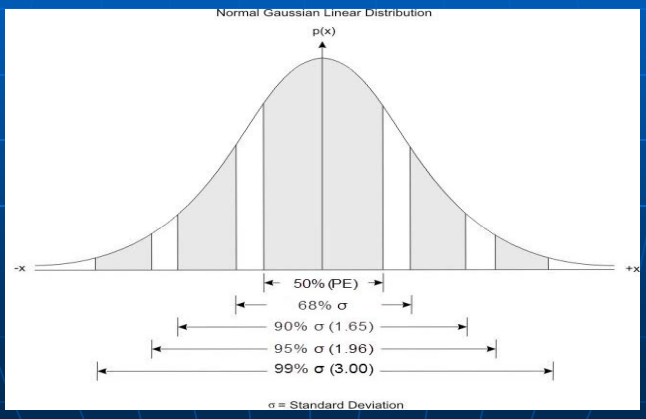
Reliability of Measurements

- Probability Distribution
  - Confidence Interval of an expected error

Probability Confidence Interval	Probability Multiplier		
	x	x,y	x,y,z
68% Interval ± σ	1.000	1.000	1.000
90% Interval ± σ	1.645	2.146	2.500
95% Interval ± σ	1.960	2.447	2.700
99% Interval ± σ	3.000	3.035	3.368

Reliability of Measurements

- Probability Distribution



Geospatial Predictive Analytics

- Data models require accuracy assessment
- Common measure of model performance
  - Root Mean Square Error, RMSE

    Square root of the average of the squares of the differences between predicted or measured values and actual or ground truth values
  - Conformity difference analysis
  - Draw backs
    - Sparse nature of the testing
    - What levels define completeness

Geospatial Predictive Analytics

- Root Mean Square Error (Conformity difference)

Univariate One Dimensional

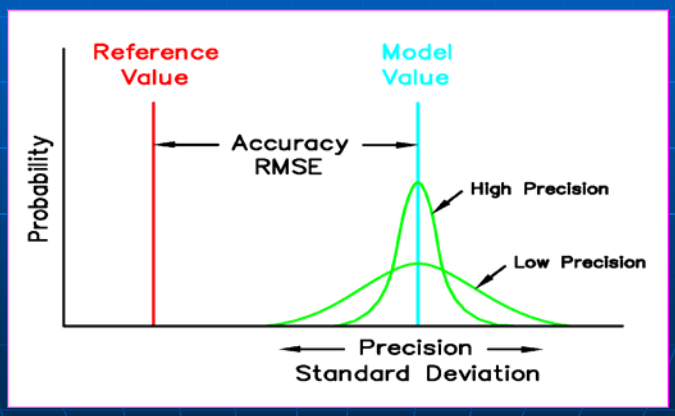
$$v_{x,y,z} = m - \tau \qquad \sigma_{x,y,z} = \sqrt{\frac{\sum v^2_{x,y,z}}{n}}$$

Bivariate Two Dimensional

$$\sigma_{x,y} = \sqrt{\sigma_x^2 + \sigma_y^2}$$

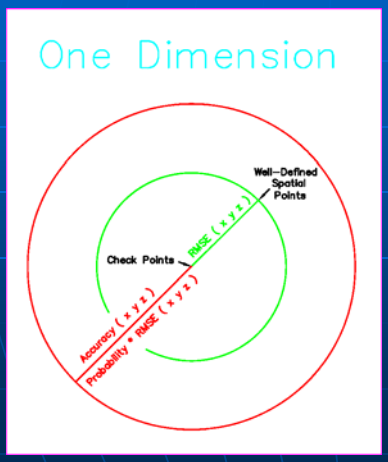
Geospatial Predictive Analytics

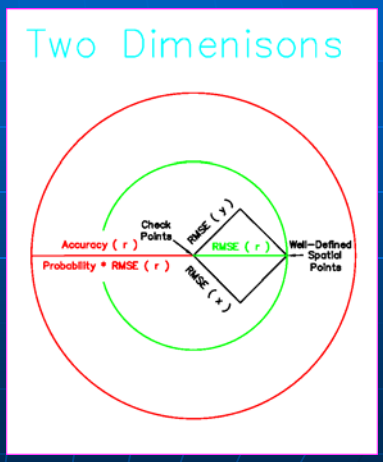
- Concepts (Precision vs. Accuracy)



Geospatial Predictive Analytics

- Concepts RMSE (Accuracy)





Mapping Standards

- What is a Standard?
- Reference Point
- Uniform Engineering or Technical Criteria
- All Digital geospatial data and Mapping Manuscripts warrant a stated standard specification
- Deviation form a defined Standard requires Documentation and Justification

Mapping Standards

- National Map Accuracy (1947)
  - Circular Map Accuracy
  - Larger than 1:20,000 – 1/30
  - Smaller than 1:20,000 – 1/50
  - ½ contour
  - Data testing by producing agency
  - GCP's surveyed at a higher accuracy
  - Statement of Compliance
  - Based upon Paper manuscripts

Mapping Standards

- Photogrammetry for Highways Committee (1968)
  - Modified NMAS
  - 90% Planimetric 1/40”, remainder 1/20”
  - 90% ½ contour, remainder contour
  - 90% spots ¼ contour, remainder ½ contour
  - Data checking by producing agency
  - GCP’s surveyed at a higher accuracy
  - Statement of compliance
  - Based upon Paper manuscripts

Mapping Standards

- ASPRS Standards (1990)
  - Established limiting RSME based on ground distances
  - Established 3 map Classes 1, 2 & 3
  - Horizontal 1/100 mapping scale
  - Vertical 1/3 contour interval
  - Spots 1/6 contour interval
  - Data checking optional,
  - Minimum 20 points, designed to access critical areas
  - GCP’s surveyed at a higher accuracy
  - Statement of compliance
  - Base upon Published Scale and Graphical Contours

Mapping Standards

- NSSDA FGDC (1998)
  - National Standard for Spatial Data Accuracy
  - Common methodology for reporting accuracy of horizontal and vertical points and positional values
  - Base upon ground distances at 95% Confidence interval
  - Does not defined thresholds, contractually user defined
  - Applies to geodetic, geospatial, Engineering etc.
  - Minimum of 20 points, designed to access critical areas
  - Statement of compliance

Mapping Standards

NSSDA ~ RMSE

NSSDA Data Checking

Horizontal

$$rmse_x = \sqrt{\frac{\Sigma(x_{data} - x_{check})^2}{n \geq 20}} \qquad rmse_y = \sqrt{\frac{\Sigma(y_{data} - y_{check})^2}{n \geq 20}}$$

$$rmse_r = \sqrt{rmse_x^2 + rmse_y^2}$$

$$Accuracy_r = 1.7308 * rmse_r$$

Vertical

$$rmse_z = \sqrt{\frac{\Sigma(z_{data} - z_{check})^2}{n \geq 20}}$$

$$Accuracy_z = 1.96 * rmse_z$$

Mapping Standards

- NSSDA FGDC (1998)
  - NMAS 1947 and NSSDA
    - Horizontal
      - NMAS CMAS = 2.1460 * RMSE x = 2.1460 * RMSE y
        = 2.1460 * RMSE r /1.4142
        = 1.5175 * RMSE r
      - Accuracy r = 2.4477 / 2.1460 * CMAS
        = 1.1406 * CMAS

Mapping Standards

- NSSDA FGDC (1998)
  - NMAS 1947 and NSSDA
    - Vertical
      - NMAS VMAS = 1.6449 * RMSE z
      - Accuracy z = 1.9600 / 1.6449 * VMAS
        = 1.1916 * VMAS

Quality Review Metrics

- Expectations

			GPS Airborne Ground Control 95%	GPS Airborne Ground Control 95%					
		Max	2.4477	1.96	GSD A/T Accuracy	A/T Expected Accuracy	A/T Expected Accuracy	A/T Estimated Accuracy	A/T Estimated Accuracy
Mapping Scale	Contour Interval	Flying Height	1:10,000 r	~ 3 rd z	x y	1/10,000 1σ x y	1/9,000 1σ z	100 lp/mm σ x y	100 lp/mm σ z
FT	FT	FT	FT	FT	FT	FT	FT	FT	FT
30	0.50	1000	0.06	0.08	0.03	0.10	0.11	0.03	0.05
60	1.00	2000	0.06	0.10	0.07	0.20	0.22	0.07	0.11
100	2.00	4000	0.10	0.20	0.13	0.40	0.44	0.13	0.22
200	4.00	8000	0.10	0.40	0.26	0.80	0.89	0.26	0.44
300	5.00	10000	0.10	0.40	0.33	1.00	1.11	0.33	0.55
600	10.00	20000	0.10	0.40	0.66	2.00	2.22	0.66	1.09

Quality Review Metrics

- Horizontal Standards

			NSSDA NMAS	NMAS	
		ASPRS	NMAS	1/30 MS	NSSDA
		68%	68%	90%	95%
	Max			2.146	2.4477
Mapping	Flying	RMSE	RMSE	CMAS	Accuracy
Scale	Height	r	r	x y	r
FT	FT			FT	FT
30	1000	0.42	0.66	1.00	1.14
60	2000	0.85	1.32	2.00	2.28
100	4000	1.42	2.20	3.34	3.81
200	8000	2.83	4.39	6.67	7.60
300	10000	4.24	6.59	10.00	11.41
600	20000	8.49	13.18	20.00	22.81

Quality Review Metrics

- Vertical Standards

Contour Interval FT	Max Flying Height FT	ASPRS Class 1 1/3 CI RMSE z FT	ASPRS Class 1 1/6 CI RMSE Spot z FT	NMAS 90% 1/2 CI z FT	NMAS 90% 1/4 CI Spot z FT	NSSDA 68% RMSE z FT	NSSDA 95% Accuracy 1.96 z FT
0.50	1000	0.17	0.08	0.25	0.13	0.15	0.30
1.00	2000	0.33	0.17	0.50	0.25	0.30	0.60
2.00	4000	0.67	0.33	1.00	0.50	0.61	1.19
4.00	8000	1.33	0.67	2.00	1.00	1.21	2.38
5.00	10000	1.67	0.83	2.50	1.25	1.52	2.98
10.00	20000	3.33	1.67	5.00	2.50	3.03	5.96

Review

- Scale $S = f / H$
- C-Factor $Cf = H / CI$
- Relief Displacement $h = d * H / r_{2,}$ $d = r_2 - r_1$
- Scale Choice Horizontal vs Vertical Requirements
  $Scale_{map} = Scale_{photo} / Enlargement$
  $Scale_{map} = f / CI * C\text{-factor}$
- End Lap Gain $S * L * [(100 - End\ Lap\ \%) / 100]$
- Side Lap Gain $S * W * [(100 - Side\ Lap\ \%) / 100]$
- Min Number of Models (Length / End Gain) round up
- Min Photos per flight Line (Length / End Gain) round up + 1
- Min Number of flight Lines (Width / Side Lap Gain) round
- Ground Control Vert = 3+1 Horiz = 2+1
- Target Size W= ps*0.002, Legs = 12*W

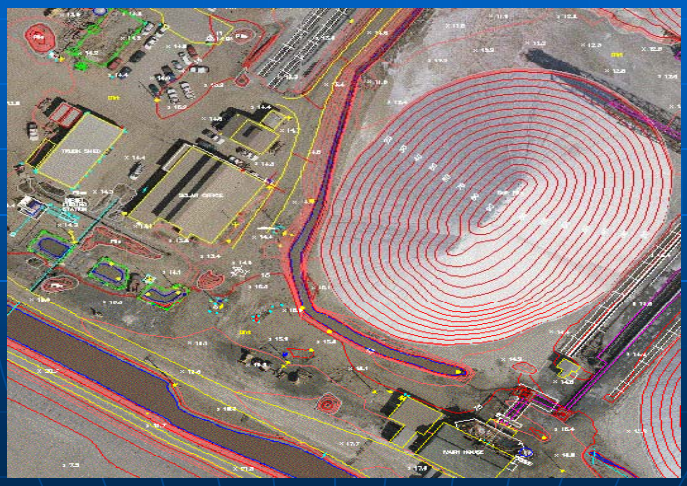
Review

- Standards
  - NMAS (1947)
    - Larger than 1:20,000 – 1/30
    - Smaller than 1:20,000 – 1/50
    - ½ contour
    - (¼ spot elevations 1968)
  - NSSDA FGDC (1998)
    - Base upon ground distances at 95% Confidence interval
    - Does not defined thresholds, contractually user defined
    - RMSE based for X,Y and Z coordinates
    - Work from defined specifications
      - May need to back in through NMAS conversions

Review

- Precision, Accuracy and Probability
- Standard Deviation
- Standard error of the Mean
- Root Mean Square Error
- Probability Factors

Ortho Contours Planimetrics



Mobile Scanning