Technical Exchange Meeting
on
Digital Orthophotos

Digital Orthophoto TEM

- Background
- Purpose
- Basis of USGS Products
- Basic Photogrammetric Mapping Process
- DEM Origins and Accuracy
- NAPP
- Evolution of Orthophoto Production Systems

Digital Orthophoto TEM

- DOQ Production Process
- Theoretical Accuracy of DOQs
- Actual Accuracy Tests
- Rules of thumb
- Closing remarks
- Discussion

Digital Orthophoto TEM

- Background
  - They said, He said, I said
  - Perhaps over-statement
  - Perhaps over-reaction
- Purpose: Clarify understanding of basic process, what we have, and what we can do

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- USGS Geospatial data largely acquired via a photogrammetric process
  - 7.5-minute topographic maps
  - DLG/DRG
  - DEM
  - DOQ

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- General photogrammetric process
  - Perspective camera
  - Stereo coverage
  - Parallax is key
  - DOQ is an approximation of a true orthophoto
  - Basic photogrammetric problem is recovering orientation of camera

USGS

Space Resection Projective Geometry

"The probable error of a single setting is 1/5 to 1/6 of the distance between two lines which are just resolved." [1]

Coordinate measurement on NAPP film:

$$\frac{1\,mm}{27\,lp}\;\frac{1\,lp}{5} = 0.007\ mm = \sigma_x = \sigma_y$$

Location measurement on film:

$$\sigma_l = \left(\sigma_x^2 + \sigma_y^2\right)^{1/2} = 0.010\,mm$$

Elevation parallax measurement on film:

$$\sigma_p = \left(\sigma_{x_1}^2 + \sigma_{x_2}^2\right)^{1/2} = 1.4\,\sigma_x = 0.010\,mm$$

Theoretical Map Precision [2]

<u>Location</u>:

$$\sigma_L = \frac{H}{f}\ \sigma_l = \frac{6096}{152.4}\ 0.01 = 0.4\ m$$

Theoretical Map Precision

Elevation:

$$\sigma_E = \frac{H}{f}\,\frac{H}{B}\,\sigma_p = \frac{6096}{152.4}\,\frac{1}{0.57}\,0.01 = 0.7\ m$$

Theoretical Map Precision

Contour Interval (CI):

$$CI = 3.3\,\sigma_E = 3.3\,(0.7) = 2.3\,m$$

Practical Map Accuracy

<u>Location</u>: Depends primarily on adjustment of stereo model to control (absolute orientation). Practical errors are two times theoretical.

$$\sigma_L \approx 2\,(0.4m) = 0.8\,m$$

Practical Map Accuracy

Elevation: Depends upon type of stereo-plotting instrument employed. Accuracy of instruments is defined by: [3]

$$c - factor = \frac{H}{Contour\ Interval}$$

Instrument	C-factor	Contour Interval (meters)
Kelsh	1200	5.1
B-8	1300	4.7
PG-2	1600	3.8
AS-11	2000	3.0
Typical	1800	3.3

DOQ Accuracy: [4]

$$S_{doq}^2(y) = S_{at}^2(y) + \frac{y^{*2}}{3H^2} S_{dem}^2$$

$$S_{at} = \pm 2 \, meters$$

$$S_{dem} = \pm 7 \, meters$$

$H = 20{,}000 \, ft$ for NAPP

$y^* = 11{,}336 \, ft$ for quarter-quad

$$S_{doq}^2(y) = (2\ m)^2 + \frac{(11{,}336\ ft)^2}{3\,(20{,}000\ ft)^2}(7\ m)^2$$

$$S_{doq}^2(y) = (2\ m)^2 + [0.11](7\ m)^2 = 4 + 5.39$$

or

$$S_{doq}(y) = \pm\,3\ meters$$

DOQ Accuracy: [5]

$$\sigma_{y_T}^2 = f^2\left[\frac{1}{(Z-Z_L)}\sigma_{Y_L}^2 + \frac{Y^{*2}}{3(Z-Z_L)^4}\sigma_{Z_L}^2 + \frac{Y^{*2}}{3(Z-Z_L)^4}\sigma_Z^2\right]$$

σ_{Y_L} *and* $\sigma_{Z_L} = 2.0\ meters = 6.56\ ft$
$\sigma_Z = 7.0\ meters = 22.96\ ft$ (DEM rmse)
$Y^* = 11{,}384\ ft$ (equal to the maximum ground Y extent, 1.875 minutes, at 40° latitude on the Clarke 1866 ellopsoid)

or

$$\sigma_{y_T}^2 = (0.5\ ft)^2 \left[\frac{1}{(20{,}000\ ft)^2}(6.56\ ft)^2 + \frac{(11{,}384\ ft)^2}{3\,(20{,}000\ ft)^4}(6.56\ ft)^2\right.$$

$$\left. + \frac{(11{,}384\ ft)^2}{3\,(20{,}000\ ft)^4}(22.96\ ft)^2\right]$$

$$\sigma_{y_T}^2 = 6.54 \times 10^{-8}\ ft^2 \quad \text{or} \quad \sigma_{y_T} = 2.56 \times 10^{-4}\ ft$$

Converting to ground units by multiplying by 40,000 yields the following error in the DOQ y-coordinate direction:

$$\sigma_{Y_T} = 10.23\ ft = \pm 3.12\ meters$$

This value falls well within the NMAS tolerance of 4.73 meters for a 1:12,000-scale product.

For different DEM accuracies:

DEM (rmse)	σ_{Y_T}
7 meters	3.19
6	2.88
5	2.67
4	2.48
3	2.32
2	2.20
1	2.13

What’s it worth and can you afford it?:

Estimated $165M for 55,000 new 3-meter DEMs to achieve less than 1 meter in additional horizontal accuracy (Based on using photogrammetric methods using existing NAPP photography and $3,000 per 7.5-minute DEM).

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- Basic Photogrammetric Mapping Process:
  - Acquire required imagery
  - Establish optimum (i.e., minimum) amount of field control
  - Extend field control via aerotriangulation process to re-establish orientation of camera
  - Collect clinometric and elevation data from stereo-models

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- DEM Origins:
  - Gestalt Photomapper II (GPM-2)
  - Profiling instruments (e.g., Wild PPO-8 and PEB8)
  - Contour conversions
  - Photogrammetric collection
  - New technologies (i.e, LIDAR and IFSAR)

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- DEM Accuracy:
  - 7-meter rmse, 30-meter post spacing
  - DEMs were derivatives from NHAP orthophotos
  - Comes from accuracy of 40-foot contour sheets
  - Reference to 10-meter DEM is misleading
  - It's a 7-meter rmse DEM with 10-meter posts

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- National Aerial Photography Program (NAPP):
  - 20,000 ft flight height with 6-inch focal length camera (resulting in 1:40,000-scale photography)
  - Quarter-quad centered
  - B&W and CIR
  - Leaf-off *vs*. leaf-on

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- Evolution of Orthophoto Production Systems:
  - T-64 Orthophotoscope
  - Gestalt Photomapper II
  - Wild PPO-8
  - Wild OR-1
  - Off-line Orthophoto Production System (OLOPS)
  - Digital Orthophotos

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- DOQ Production Process:
  - In general, it is the same as the photogrammetric mapping process
  - After determining orientation of the exposure station and using an DEM, each pixel of a digital image is “re-projected” into its proper location, removing displacements due to relief

DOQ Processing

How high can you fly?

$$\frac{\sigma_h}{H} = \frac{\sqrt{2}\,\sigma}{(B/H)\,f}$$

$\sigma =$ standard error of measured coordinates

For regular vertical photography, B/H = 0.6 and f = 150 mm:

$$\sigma_h = \frac{\sqrt{2}\,(0.03)}{0.6 \times 150}\,H = 0.000471\,H \approx 0.05\%\,H$$

For NAPP Photography:

$$\sigma_h = 0.05\%(20{,}000) = 10\,ft \text{ or } 3.05 \text{ meters}$$

Similarly, the standard error of the horizontal position:

$$\sigma_R = \frac{H\,\sigma}{f} \qquad \text{or} \qquad \sigma_R = 0.02\%\,H$$

For NAPP photography:

$$\sigma_R = 0.0002\,(20{,}000) = 4.0\ ft = 1.2\ meters$$

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- Rules of thumb:
  - Vertical accuracy: 0.02% to 0.05% of flying height
  - Horizontal accuracy: 0.01% to 0.02% of flying height
  - Use C-factor of 1800 or less

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- Closing remarks:
  - Best overall results given where we started and the DEMs that were used
  - Need for better, faster and cheaper
  - Can we afford it and will it be timely?
  - Additional field control will not improve aerotriangulation results
  - In general, flying lower gives you better results

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- Closing remarks (cont'd):
  - Flying lower means more cost
  - Image resolution is a bigger factor than absolute accuracy
  - True quality assurance difficult

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- Future DOQ questions:

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