Local Elevation Surface Modeling using GPS-Derived “Point Clouds”
Study Area Overview

Topographic Background

NAIP with Roads and Streams

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Public DEM Models of Study Area

National Elevation Dataset

DEM24

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NED Hill Topography Detail

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DEM24 Hill Topography Detail

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Surprising DEM Metadata

National Elevation Dataset

• RMS: 2.44 meters (8.0 feet)
• NMAS: 3.99 m (13.09 feet)
  @ 90% confidence
• NSSDA: 4.75 m (15.58 feet)
  @ 95% confidence

(Absolute vertical accuracy measured against 13,000 National Geodetic Survey benchmarks across US and given by confidence level)

VCGI DEM24 Metadata

• Desired RMS: 7 meters (23 feet)
• Allowable RMS: 15 meters (49 feet)

(These figures are believed to be conservatively based on the production goals for USGS 7.5 minute DEMs)
Equipment and Software Employed

Trimble GPS Resources

• *GeoExplorer XT Handheld* Field Computer (2008 Series)
• *Hurricane* External Antenna
• *Terrasync* Field Software
• *Pathfinder Office* Desktop Software

ESRI GIS Software

• *ArcGIS Desktop (ArcEditor Level)*
• *Spatial Analyst* Extension
• *3D Analyst* Extension

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Overview of Methodology

**GPS Data Collection/Export**
- Walk the area of interest, randomly or systematically, collecting “Not in Feature” GPS positions at 1-second intervals
- Correct positions by post-processing and export as a point shapefile
- Repeat as needed to achieve full area coverage

**GIS Processing/Presentation**
- Select a suitable data structure and parameters for surface representation (TIN, raster, terrain)
- Merge data from multiple days of collection and convert to chosen format
- Display, analyze and evaluate the resulting elevation surface

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Necessary Conditions for Success

“Good” Horizontal Positions

• NED’s 10-meter post spacing represents the horizontal spatial resolution we seek to improve upon

• We should check how well the nominally “sub-meter” GPS hardware/software system performs under the field conditions actually experienced

“Not Too Bad” Elevations

• NED elevation absolute accuracy is 8 feet RMS, 16 feet with 95% confidence

• DEM-based elevation contours are generally drawn at 20-foot intervals

• Averaging of individual GPS elevation values will be needed to improve upon a NED elevation surface

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Data Collection Focus Areas

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1st GPS Data Capture Illustration

North Pasture Data Capture

Position Detail with Elevations

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2\textsuperscript{nd} GPS Data Capture Illustration

Spruce Grove Data Capture

Position Detail with Elevations

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Spruce Grove Route Detail
Further Look at Spruce Grove Data

Spruce Grove GPS Positions

Track with Precision Circles

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Horizontal Positional Uncertainty

“Best Day” Estimate

<table>
<thead>
<tr>
<th>Range</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>0-15cm</td>
<td>27.5%</td>
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<tr>
<td>15-30cm</td>
<td>40.9%</td>
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<tr>
<td>30-50cm</td>
<td>18.0%</td>
</tr>
<tr>
<td>0.5-1m</td>
<td>10.5%</td>
</tr>
<tr>
<td>1-2m</td>
<td>2.7%</td>
</tr>
<tr>
<td>2-5m</td>
<td>0.5%</td>
</tr>
<tr>
<td>&gt;5m</td>
<td>-</td>
</tr>
</tbody>
</table>

“Best Day” Detail

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## Horizontal Positional Uncertainty

### Accuracy Estimate Statistics

Estimated accuracies for 367,989 corrected positions

<table>
<thead>
<tr>
<th>Range</th>
<th>%</th>
<th>Cum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15cm</td>
<td>2.54</td>
<td>2.54</td>
</tr>
<tr>
<td>15-30cm</td>
<td>2.43</td>
<td>4.96</td>
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<tr>
<td>30-50cm</td>
<td>44.66</td>
<td>49.63</td>
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<tr>
<td>0.5-1m</td>
<td>37.00</td>
<td>86.62</td>
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<tr>
<td>1-2m</td>
<td>11.32</td>
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<tr>
<td>2-5m</td>
<td>1.60</td>
<td>99.54</td>
</tr>
<tr>
<td>&gt;5m</td>
<td>0.11</td>
<td>99.65</td>
</tr>
</tbody>
</table>

### Cumulative Data Collection

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Elevation Data Range Comparison
Elevation Data SD Comparison
West Slopes Elevation SDs

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Example Red Cell Elevation Stats
Averaging Noisy Values in Raster Cells

**Law of Large Numbers**

- Sample means become more concentrated about the universe (true) mean as the sample size grows.

**Central Limit Theorem**

- The expected value of a sample mean is the true mean.
- The standard deviation of sample means decreases with the square root of sample size.

**Tchebycheff’s Inequality**

- The probability that a randomly sampled value differs from the true mean by more than $K$ standard deviations will not exceed $1/K^2$ (regardless of the shape of the distribution).
Cell Size vs. Point Count Sufficiency

10m Cells

7m Cells

5m Cells

3m Cells

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Unavoidable GPS Data Gaps
Low-Pass Spatial Filtering
(is not equivalent to resampling)

Original Image  Low Pass Filter  3X Larger Cells

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Single-Cell Spatial Filtering

Unfiltered  First Pass  Second Pass  Third Pass

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Low-Pass Spatial Filtering

Noisy Image  First Pass  Second Pass  Third Pass

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Validating an Elevation Surface

North Pasture

South Flats

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Hilltop Area Contours

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Expanded Area Validation (Method 1)

- View encompasses all four focus areas (~40 acres)
- Colored 10-foot contours were developed using two fully independent data subsets
  - odd days – magenta
  - even days – orange
- Heavy black contours were developed using combined (odd + even) data

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Expanded Area Validation (Method 2)

- Colored and black 10-foot contours as before
  - odd days – magenta
  - even days – orange
  - odd + even – black
- Background colors indicate magnitude of odd-even MSL differences
  - 0 - 2.5 feet – dark green
  - 2.5 – 5 feet – light green
  - 5 – 7.5 feet – yellow

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GPS-NED Elevation Differences

- 40-acre extent as before
- GPS surface believed reliable to plus/minus 5 feet
- Colors indicate magnitude of GPS and NED MSL differences
  - 0 - 2.5 feet – dark green
  - 2.5 – 5 feet – light green
  - 5 – 7.5 feet – yellow
  - 7.5 – 10 feet – orange
  - 10 – 12.5 feet - red

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GPS-NED Contour Comparison

GPS Surface  NED Surface

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Reflection and Conclusions

• Field methods
• GPS equipment/software performance
• GIS processing and tools
• Practicality
• General satisfaction
• What’s next?
Contact Information

GPS/GIS Mapping
Data Collection Services and
Custom Map Products for
Individuals and Organizations
John G. Whitman, Jr.
Green Forest Farm
P.O. Box 177
Readsboro, VT 05350
(802) 423-9917
WhitmanJ2@myfairpoint.net

Not all who wander are lost!