Emerging Surveying and Mapping Technologies

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OSBEELS Symposium
September 14, 2018
Salem, Oregon
“Boots-on-the-ground” field surveys
**Desired improvements**

<table>
<thead>
<tr>
<th>Spatial coverage (area)</th>
<th>↑</th>
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<tbody>
<tr>
<td>Time</td>
<td>↓</td>
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<tr>
<td>Cost</td>
<td>↓</td>
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<tr>
<td>Spatial uncertainty</td>
<td>↓</td>
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</tbody>
</table>

*Can’t be done, due to inherent tradeoffs between these goals!*
Alternative: moving survey platform

- Nearly certain to cover more ground quickly
- What’s the tradeoff? Accuracy
- Objective function:

\[
\min \{ \text{cost} + \text{time} \}
\]
\[
\text{subject to } \{ \text{accuracy} \leq \text{spec} \} 
\]
Inherent Tradeoffs

In the diagram, the relationship between speed (m/s) and uncertainty (m) is depicted on a logarithmic scale. The data points for different types of vehicles are shown, illustrating the inherent tradeoffs in terms of speed and accuracy.
Emerging tools & technologies

• Autonomous/unmanned vehicles
  • UAS, ASVs, ROVs
  • UAS-based lidar and Structure from Motion (SfM) photogrammetry

• Direct georeferencing: GNSS-aided INS
  • Smaller, cheaper, lighter carrier-base based GNSS and MEMS INS

• New advances in airborne and mobile lidar
  • Single photon and Geiger mode lidar
  • Topographic-bathymetric lidar
  • Satellite-based lidar

• How do we quantitatively assess, compare, and optimize for our operational use?
UAS + SfM Photogrammetry

• SfM
  • Relatively new photogrammetric approach
  • Leverages advanced image matching algorithms from the field of computer vision
  • Can work with a wide range of viewing geometries and consumer-grade cameras
    • Well suited to UAV imagery!
  • Highly automated, easy to use software
SfM Workflow

UAS flight(s)

Overlapping imagery (~80% endlap & sidelap)

Keypoint computation & matching (e.g., SIFT)

Sparse point cloud

Bundle adjustment

Camera params (IO)

End products: orthos, DEMs, 3D meshes

MVS

Dense point cloud

GCPs
Empirical accuracy assessments, per ASPRS Positional Accuracy Standards for Digital Geospatial Data & FGDC NSSDA

\[
RMSE_z = \sqrt{\frac{\sum (z_{\text{data}_i} - z_{\text{check}_i})^2}{n}}
\]

\[
\text{Accuracy}_z = 1.96(RMSE_z)
\]

\geq 20 \text{ well-distributed checkpoints}

RTK GNSS

Post-processed static GNSS
1. Generate Model
2. Texture Model
3. Add Lighting to Scene
4. Add Cameras
5. Render Imagery
6. Postprocess Imagery

- Lens Distortion
- Vignetting
- Gaussian Noise
- Salt/Pepper Noise
- Gaussian Blur
7. Process Using Commercial SfM
8. Generate Sparse Pointcloud
9. Generate Dense Pointcloud
10. Compare Dense Pointcloud to Mesh
11. Compute Cloud to Mesh Distances
Qualitative Results

Lower Photoscan Dense Quality = round corners
Quantitative Results

Compute error by comparing to groundtruth mesh
Another option: Direct Georeferencing

- GNSS antennas
- Velodyne Puck Lidar
- GNSS-aided INS

Diagram:
- IMU: orthogonal triads of accelerometers and gyros
- Inertial sensor data
- INS mechanization & error controller
- Position, Velocity, Attitude
- Error estimates
- GNSS receiver
- GPS observables
- Kalman filter
- GNSS base station observables
- Blended navigation solution
DG for UAS-lidar

Example Point Cloud Cross Section

- FLIGHT PATH 2
- FLIGHT PATH 1
- GRASS FIELD
- TREES
- PARKED CAR
Topographic-Bathymetric Lidar

$H = 300-400 \text{ m (typical)}$

Sea surface

Sea floor

Intensity

Time
Topo-Bathy Lidar Uncertainty Modeling

\[ \Sigma_{ws} = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_y^2 & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_z^2 \end{bmatrix} = J \Sigma_m J^T \]
Subaerial Uncertainty

\[
\begin{bmatrix}
    x_l \\
    y_l \\
    z_l
\end{bmatrix} = \begin{bmatrix}
    x_t \\
    y_t \\
    z_t
\end{bmatrix} + R_l^b R_s^b \begin{bmatrix}
    0 & 0 \\
    0 & -\rho \\
    -\rho & 0
\end{bmatrix} \begin{bmatrix}
    \Delta x \\
    \Delta y \\
    \Delta z
\end{bmatrix} + \Delta \begin{bmatrix}
    \Delta x \\
    \Delta y \\
    \Delta z
\end{bmatrix}
\]

\[
\Sigma = \begin{bmatrix}
    \sigma_X^2 & \sigma_{XY} & \sigma_{XZ} \\
    \sigma_{XY} & \sigma_Y^2 & \sigma_{YZ} \\
    \sigma_{XZ} & \sigma_{YZ} & \sigma_Z^2
\end{bmatrix} = J \begin{bmatrix}
    \sigma_{\alpha} & \ldots & 0 \\
    \vdots & \ddots & \vdots \\
    0 & \ldots & \sigma_{\rho}
\end{bmatrix} j^T
\]
Combining component uncertainties

\[ \text{Total Uncertainty} = \sqrt{\text{subaerial}^2 + \text{subaqueous}^2 + \text{datum}^2} \]
Photon Elevations along MABEL Trackline (Channel 11)

Comparison with Reference Bathymetry

Reference & MABEL Elevations

WGS84 Height (meters)

Elevation Differences

RMS = 0.7 m

“data curtain”
Unsolved Challenges

• When more data becomes too much data
  • Big data, AI/machine learning, cloud processing
  • Data -> information -> insight
• Linking empirical accuracy assessments and modeled uncertainties
• Sensor/technology-neutral assessment methods
• Standards, guidelines, and best practices!!
  • In an era of accelerating growth in new mobile/airborne surveying and mapping technologies, need ways of dismissing hype and ensuring appropriate technology use to ensure specs of job are met
Acknowledgements

• Grad Students
  • Richie Slocum
  • Chase Simpson
  • Nick Forfinski-Sarkozi
  • Matt Gillins

• Postdocs
  • Jaehoon Jung
  • Firat Eren (UNH)
Acknowledgements

This work was supported by the following grants:

- NASA Research Opportunities in Space and Earth Sciences (ROSES): Grant # NNX15AQ22G: “ICESat-2 Algorithm Development for the Coastal Zone”
- Department of the Interior, USGS: AmericaView Grant # G14AP00002: “OregonView”
- NOAA CIMRS Grant # NA11OAR4320091A:
  - “Seafloor Reflectance Mapping from EAARL-B Topobathymetric Lidar Data in the U.S. Virgin Islands” (2015)
  - “Enhanced EAARL-B Lidar Processing and Waveform Analysis for the U.S. Virgin Islands” (2016)
  - Optimizing UAS Imagery Acquisition and Processing for Shallow Bathymetric Mapping (2017-2018)
- ODOT, Agreement 30530, WO 16-05: “Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles”
Questions

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