UAS-based Lidar: Performance comparison of Four Lidar systems

Qassim Abdullah, Woolpert

AFB80 Committee Summer 2019 Meeting – July 22-24, 2019 Daytona Beach, FL
The Project

- Woolpert was contracted by CSU-Fresno Foundation to acquire data over their testing field using UAS-based imagery and lidar
- Woolpert flew eBee X RTK UAS for imagery and four lidar systems
- I will brief you on our analysis of the data
CSU Testing site, North of Fresno California
400x400 meter
The Digital Imaging Technology
We deployed Sensefly eBee X with RTK/PPK Capability
CSU Testing Site

- 81 Targeted GCPs
- Surveyed to accuracy of:
  - Vertical one-sigma = 0.3-cm
  - Horizontal one-sigma = 1.0-cm
- Woolpert was provided with 40 checkpoints for the analysis
Ground Controls and Accuracy – The eBee X Evaluation

<table>
<thead>
<tr>
<th>Accuracy Term</th>
<th>Residual Values (m)</th>
<th>Delta Z after Z-bias Removed (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Error</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>Standard Deviation (StdDev)</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>Root Mean Squares Error (RMSE)</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>Radial RMSE</td>
<td>0.039</td>
<td>0.039</td>
</tr>
<tr>
<td>NDSR Horiz Accuracy at 95% accuracy Level</td>
<td>0.119</td>
<td>0.119</td>
</tr>
<tr>
<td>NDSR Vert Accuracy at 95% accuracy Level</td>
<td>0.058</td>
<td>0.058</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracy Term</th>
<th>Processing Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of GCPs in AT</td>
<td>A</td>
</tr>
<tr>
<td>Number of Check Points</td>
<td>9</td>
</tr>
<tr>
<td>RMSE E (m)</td>
<td>0.015</td>
</tr>
<tr>
<td>RMSE N (m)</td>
<td>0.013</td>
</tr>
<tr>
<td>Radial RMSE N,E (m)</td>
<td>0.020</td>
</tr>
<tr>
<td>RMSE Elev. (m)</td>
<td>0.029</td>
</tr>
<tr>
<td>Horizontal Accuracy at 95% (m)</td>
<td>0.035</td>
</tr>
<tr>
<td>Vertical Accuracy at 95% (m)</td>
<td>0.058</td>
</tr>
</tbody>
</table>
The Lidar Technology
Anatomy Of a UAS-based Lidar System

Images courtesy, Lidar USA, DJI, and VECTORNAV
Dynamics governing putting Lidar system on a drone

- Has to be light weight
  - Limited physical size and weight impact its performance
    - Lower power laser
    - Lower performance GPS and IMU
- Has to be affordable to fly it on a small drone over a small size project
  - Low cost lidar means degraded performance
    - Low cost lidar means lower quality laser, GPS, and IMU
    - Lower quality sub-systems means lower quality points cloud
We deployed four Lidar systems leased from Lidar USA through a contract with MODUS.
Lidar Evaluation

Points Cloud Density
### Points Density, standard processing

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Ground ONLY</th>
<th>All Classes (pts/m²)</th>
<th>Nominal Point Spacing (m)</th>
<th>Density (pts/m²)</th>
<th>Nominal Point Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MiniVUX</td>
<td>7.6</td>
<td>155</td>
<td>0.36</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Quanergy_M8</td>
<td>9.6</td>
<td>570</td>
<td>0.32</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Velodyne HDL32</td>
<td>7.5</td>
<td>521</td>
<td>0.365</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Velodyne VLP16</td>
<td>4.7</td>
<td>305</td>
<td>0.461</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

### Points Density, after allowing some noisy points**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Ground ONLY</th>
<th>All Classes (pts/m²)</th>
<th>Nominal Point Spacing (m)</th>
<th>Density (pts/m²)</th>
<th>Nominal Point Spacing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MiniVUX</td>
<td>42</td>
<td>155</td>
<td>0.15</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Quanergy_M8</td>
<td>76</td>
<td>570</td>
<td>0.12</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Velodyne HDL32</td>
<td>56</td>
<td>521</td>
<td>0.13</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>Velodyne VLP16</td>
<td>18</td>
<td>305</td>
<td>0.23</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

** Used "Classify above ground" routine
Lidar Evaluation
Features Mapping
Lidar Evaluation

Riegl Mini VUX
Scan Pattern  Intensity Quality
Trees Penetration
Road Profiles
G r a s s y  G r o u n d
Lidar Evaluation
Velodyne HDE 32
Scan Pattern

Intensity Quality
Roofs
Missing Power Lines
Trees Penetration
Road Profiles
Grassy Ground
Lidar Evaluation

Velodyne VLP16
Roofs
Trees Penetration
Road Profiles
Grassy Ground
Lidar Evaluation
Quenergy M8
Scan Pattern

Intensity Quality
Roofs - Classification
Roofs
3 lines
registration
Missing Power Lines
Trees Penetration
Road Profiles
Grassy Ground
Lidar Evaluation

Vertical Accuracy
# Accuracy Evaluation using 40 check points

## Table of Accuracy Terms

<table>
<thead>
<tr>
<th>Accuracy Term</th>
<th>Velodyne HDL 32E</th>
<th>Velodyne HDL VLP16</th>
<th>Riegl MiniVUX</th>
<th>Quenergy M8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (m)</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Minimum (m)</td>
<td>-0.162</td>
<td>-0.138</td>
<td>-0.093</td>
<td>-0.128</td>
</tr>
<tr>
<td>Maximum (m)</td>
<td>0.149</td>
<td>0.100</td>
<td>0.071</td>
<td>0.052</td>
</tr>
<tr>
<td>StDEV (m)</td>
<td>0.082</td>
<td>0.054</td>
<td>0.038</td>
<td>0.042</td>
</tr>
<tr>
<td>RMSE_v (m)</td>
<td><strong>0.081</strong></td>
<td><strong>0.054</strong></td>
<td><strong>0.038</strong></td>
<td><strong>0.042</strong></td>
</tr>
<tr>
<td>Accuracy at 95% (m)</td>
<td>0.159</td>
<td>0.105</td>
<td>0.074</td>
<td>0.082</td>
</tr>
</tbody>
</table>
The Wrong and Right Practices In Geospatial Data Accuracy Verification
**Statement of the problem:**

- We quantify product accuracy ignoring the errors in the surveyed check points.
- Our surveying techniques are approximating the datum, i.e., producing pseudo datum.
- Currently, we are evaluating the closeness of data to the pseudo datum and not the datum.

**Current practice:**

Product accuracy = Errors in fitting products to check points

**Correct practice:**

Product accuracy = Errors in fitting products to check points + check points accuracy
Why So

Long ago, geospatial products and mapping technologies were less accurate:

- Ortho imagery produced with low resolution, DOQQ is 1 meter GSD
- Maps were produced with small scale
- Therefore, errors in control/check points were usually ignored as it was considered negligible
Why Now

- Geospatial products today are very accurate
- We are heading toward more accurate datum in 2022
- Drone are collecting imagery with 1-cm GSD and producing highly accurate products
- Lidar is providing accuracy in the range of 1.5 to 10 cm
- ASPRS standards support high accuracy
- We just can not continue our wrongful practice
How should we express product accuracy?

**Photogrammetry:**

*Aerial Triangulation Accuracy* = The fit to the GCPs + the accuracy of the GCPs

*Ortho Accuracy* = The fit to check points + the accuracy of the GCPs

**Lidar:**

*Lidar Accuracy* = The fit to check points + the accuracy of the GCPs
Example

- Surveyed check points are used to verify ortho and DSM accuracy.
- The check points were surveyed using RTK techniques with horizontal accuracy of RMSE $= 2\text{-cm}$ and vertical accuracy of RMSE $= 3\text{-cm}$

**Ortho QC** using the check points resulted in $\text{RMSE}_{xy} = 2.5\text{-cm}$

**DSM QC** resulted in $\text{RMSE}_z = 2.7\text{-cm}$

**Final Ortho Accuracy** $= 2.5\text{-cm} + 2\text{-cm}$ (vectors arithmetic should be used here)

**Final DSM Accuracy** $= 2.7\text{-cm} + 3\text{-cm}$ (vectors arithmetic should be used here)

Currently, the ortho is labeled with 2.5-cm accuracy and the DSM with 2.7-cm accuracy
Thank you!
The Best of All Worlds: Data Fusion and the Hybrid DSM
Aerial Lidar + MMS + UAS

**Aerial Lidar:**
Points Density: up to 30 pts/m²
Accuracy(v) RMSE = 6 to 15 cm

**MMS:**
Points Density: 2,000 to 6,000 pts/m²
Accuracy(v) RMSE = 1.5 cm

**UAS:**
Points Density: 40 to 1000 pts/m²
Accuracy(v) RMSE = 5 to 15 cm
Integrated Surfaces
Collect, digitize and attribute all elements of the project
Advantages of Point Clouds from UAS Imagery

- Birds Eye View, i.e. beyond MMS coverage
- Affordable approach
- Easy to deploy
- Easy to process
- Excessive overlap
Limitations of Point Clouds from Imagery

- Less accurate than LiDAR
- No tree penetration
- FAA Regulations
Strength of Mobile Mapping System Technology (MMS)

- Best positional accuracy RMSE = 0.05’ or better
- Very dense points cloud 2000 to 6000 points/m2
- Oblique/ground view versus top-down aerial
- Dual Lidar-imagery acquisition
Limitations of Mobile Mapping Systems (MMS)

- Only on driven roads
- Limited range
- Not suitable for rural environments
Limitations of Aerial LiDAR

- Lower point cloud density as compared to MMS
- Limited positional accuracy for DOT’s road design projects
- Not suitable for small projects
- Obscured areas
Data Fusion
The Petersburg/Overman Roads Intersection Improvement
Hybrid Approach to Project Data

Accuracy Verification
### MMS Data

**Accuracy Validation**

<table>
<thead>
<tr>
<th>Number of Check Points</th>
<th>79</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Error</strong></td>
<td>0.023 ft.</td>
</tr>
<tr>
<td>Standard Deviation (StDEV)</td>
<td>0.037 ft.</td>
</tr>
<tr>
<td><strong>Root Mean Squares Error</strong></td>
<td>0.043 ft.</td>
</tr>
<tr>
<td>NSSDA Vert Accuracy at 95%</td>
<td>0.085 ft.</td>
</tr>
</tbody>
</table>
UAS Data

UAS 100 ft. AGL Altitude
### UAS Data

**Accuracy Validation**

<table>
<thead>
<tr>
<th>Number of Check Points</th>
<th>73</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Error</strong></td>
<td>0.085 ft. 0.026 m</td>
</tr>
<tr>
<td><strong>Standard Deviation (StDEV)</strong></td>
<td>0.130 ft. 0.040 m</td>
</tr>
<tr>
<td><strong>Root Mean Squares Error</strong></td>
<td>0.154 ft. 0.047 m</td>
</tr>
<tr>
<td>NSSDA Vert Accuracy at 95%</td>
<td>0.302 ft. 0.092 m</td>
</tr>
</tbody>
</table>
Aerial LiDAR: Existing Ohio Statewide Imagery Program (OSIP)

Accuracy Validation

<table>
<thead>
<tr>
<th>Number of Check Points</th>
<th>197</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Error</td>
<td>0.47 ft.</td>
</tr>
<tr>
<td>Standard Deviation (StDEV)</td>
<td>0.16 ft.</td>
</tr>
<tr>
<td>Root Mean Squares Error (RMSEz)</td>
<td><strong>0.50 ft.</strong></td>
</tr>
<tr>
<td>NSSDA Vert Accuracy at 95% Confidence Level</td>
<td>0.98 ft.</td>
</tr>
</tbody>
</table>

Aerial LiDAR Data
Hybrid Approach to Project Data Preparation
**STEP 1:** Preparing MMS Data

Only good around driven roads
**STEP 2:** Preparing UAS Data

Drone-based DSM
STEP 3: Preparing Aerial Lidar Data

Aerial LiDAR from OSIP
**STEP 4:** Merging Aerial LiDAR + UAS DSM
**STEP 5:** Merging Aerial LiDAR + UAS DSM + MMS DSM
(The Hybrid DSM)
Hybrid Approach to Project Data

Final Outcome: Accuracy on Demand
Data Fusion provides accuracy where you need it most!

<table>
<thead>
<tr>
<th>Product Specification</th>
<th>Hybrid Product Accuracy**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrain surface accuracy as verified using independent check points</td>
<td>** Type A</td>
</tr>
<tr>
<td>RMSEₜ ≤ 0.06 ft.</td>
<td>RMSEₜ ≤ 0.10 ft.</td>
</tr>
</tbody>
</table>

** Type A = MMS lidar, Type B = UAS imagery-based points cloud, Type C = State wide lidar program
Hybrid Approach to Project Data

Products Development and Final Deliverables
Resulting Product: Seamless Dataset
Thank you!