Accuracy of Stockpile Volume Determination Using UAS Photogrammetry

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Why measure stockpile volumes?

- Civil and mining engineering projects often require large amounts of material to either be removed or added to a site as part of the earthworks portion of the project.
- Earthworks are a considerable portion of overall cost to a project.
- Contractors are often paid by volume and compliance to design can be checked by volume.
- Calculation of volume utilises spot heights to develop contours or Digital Surface Models (DSM).
Methods of determining stockpile volume

- Total station
- RTK GNSS
- Laser Scanner
- Aerial LiDAR
- Unmanned Aerial Systems (UAS)

Photogrammetry
Direct Techniques

Total Station & RTK GNSS

Advantages:
• Data size smaller therefore easier to handle
• Captures only points of interest
• Cost efficient for small areas

Disadvantages:
• Must physically interact with surface
• Safety concerns: hazardous material, unstable surface etc.
• Time consuming to conduct dense survey
• Interpretation of surface
Indirect Techniques

Laser Scanning, LiDAR & UAS Photogrammetry

Advantages:
- Captures all features with a high density of points
- UAS & LiDAR can cover vast areas efficiently
- Does not require interaction with surface

Disadvantages:
- Generates huge amounts of data
- Laser Scanning has difficulty if top surface of stockpile is uneven
- Aerial techniques struggle to capture near vertical surfaces
UAS Photogrammetry

- Occupy niche field where large area and point density is required
- Affordability has allowed more survey businesses to enter the UAS market
- Although utilizing old principles, conformation of uncertainties is difficult and not readily understood
- Increasing automation of processing increases productivity. But does the program execute calculations the way the surveyor assumes it does?
- senseFly eBee RTK and 3DR X8 to be used
Site Selection

- Helensburgh Waste Facility
- Laser scan and RTK GNSS comparison using two small stockpiles on the west of the site
- Comparison with LiDAR of the large waste hill that has significant amounts of vegetation
RTK survey Comparison

- Small stockpiles were surveyed using Leica Viva GS15 and then compared to initial eBee RTK flight.
- 0.5m DSM extracted over the small stockpile area, equating to 5150 points.
- Civilcad was used generate a DTM and then compare computed volumes
- Difference of 2%.
- Over the DTM surface area of 1145m² that’s roughly a 5cm thick blanket.

<table>
<thead>
<tr>
<th>Method</th>
<th>Area $m^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTK</td>
<td>2567</td>
</tr>
<tr>
<td>UAS</td>
<td>2622</td>
</tr>
<tr>
<td>Difference</td>
<td>55</td>
</tr>
</tbody>
</table>
Terrestrial Laser Scanning

- Terrestrial laser scanning is a suitable truthing method for stockpile volume determination
- Produces a dataset very similar to that of UAS photogrammetry. Making it very suitable for comparison.

Leica MS50 (multistation)
- Scanning distance accuracy: at 50m 1-0.6mm depending on Hz mode
- Angle accuracy: 1"
- Point capture rate: 1000pts/sec
- Can traverse normally like a total station and then perform laser scans
Laser Scanning Fieldwork

- Two ground control points used as control.
- 5 stations around the stockpile and 1 atop it. Stations on top needed due to the shape of the stockpile.
- ≈1hr to complete fieldwork
- Scan settings; 0.3m spacing at 40m, angular spacing of ≈25’
- Each scan took approximately 7 minutes.
Output

• Point cloud output from laser scan is very comparable to that generated by UAS photogrammetry.
• A 0.5m grid is extracted from these point clouds for stockpile volume calculation.
• Laser scan details vertical surfaces better than UAS.
Volume Computation

- Magnet Office used to calculate volumes.
- Common boundary with interpolated heights to create a base plate DTM. Resolves errors between height datums.
- Volume is calculated as a difference between the base original DTM using a prismoidal method.
- Common area: 1056.3m$^2$
- Each UAS scenario is compared against the results of the laser scan.
X8 Flights

- Total of 12 flights were completed using the 3DR X8 UAS. Three of the flights were used to create 4 scenarios.

<table>
<thead>
<tr>
<th>Flight #</th>
<th>Height ATO (m)</th>
<th>Overlap (%)</th>
<th>Camera Angle (°)</th>
<th>Flight Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
<td>80</td>
<td>0</td>
<td>E-W</td>
</tr>
<tr>
<td>4</td>
<td>120</td>
<td>80</td>
<td>22</td>
<td>E-W</td>
</tr>
<tr>
<td>12</td>
<td>120</td>
<td>80</td>
<td>30</td>
<td>N-S</td>
</tr>
</tbody>
</table>
Comparison Scenarios

- Four scenarios developed in order to determine the effect of increased image coverage and camera orientation.
- Scenarios 1 and 2 establish the effect of off nadir camera orientation on volume calculation.
- Scenario 3 investigates implications of adding off nadir imagery to scenario 1.
- 4 is a best case scenario combining two flights that are in perpendicular flight paths and with off nadir camera orientation.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Flight(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Single flight with a nadir facing camera configuration</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>Single flight with an off nadir camera configuration</td>
</tr>
<tr>
<td>3</td>
<td>1, 12</td>
<td>Two flights using an off nadir and nadir camera configuration</td>
</tr>
<tr>
<td>4</td>
<td>4, 12</td>
<td>Two flights both using an off nadir camera configuration</td>
</tr>
</tbody>
</table>
Scenarios 1 & 2

- Scenario 1 is a similar configuration to the RTK comparison. The results are similar in magnitude being 2.4% difference.
- Scenario 2 gives a closer result to the laser scan.
- Demonstrates that an off nadir camera configuration gives closer volume calculation results than nadir imaging.
- Average height difference of 24mm and 10mm respectively.

<table>
<thead>
<tr>
<th></th>
<th>Volume ($m^3$)</th>
<th>Difference ($m^3$)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Scan</td>
<td>1095.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
<td>1121.4</td>
<td>25.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>1106.4</td>
<td>10.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Scenario 3 & 4

- The addition of off nadir images improves the accuracy of the volume results for scenario 3 when compared to 1.
- The combination of cross path off nadir imagery in scenario 4 gave the best results coming very close to that determined by the laser scan.
- Scenario 4 deviates from the volume determined by the laser scan in the opposite direction than all the previous scenarios.
- Average height difference of 16mm and -3mm respectively.

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<th>Difference ($m^3$)</th>
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<tbody>
<tr>
<td>Laser Scan</td>
<td>1095.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 3</td>
<td>1112.5</td>
<td>16.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>1092.6</td>
<td>-3.0</td>
<td>-0.3</td>
</tr>
</tbody>
</table>
Conclusion

- Following factors increase the accuracy of determining stockpile volume:
  - Increasing number of images.
  - Off nadir imaging.
  - Capture images of the subject area from a multitude of directions.

- UAS photogrammetry is a competitive alternative to laser scanning for determining stockpile volumes. Especially when its ability to be scaled up to measure large numbers of stockpiles is taken into account.

- Much of the uncertainty of determining volume comes from the volume measurement base surface. Without a survey of the ground before a stockpile is created, its base cannot be determined without the use of interpolation or some other estimation.
Questions?
References


