Systematic Height Errors in UAS Photogrammetric Mapping

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GNSS for UAS Photogrammetric Mapping
Background

- **Consumer grade cameras** usually are used
- DSM accuracy ±5cm by UAS manufacturers
- In practices, however, point heights derived from near nadir images are higher than GNSS/RTK surveyed results
- Surveyors and publications have reported this issue
- Practical investigations were conducted on this type of errors
- Best practices are suggested for precise UAS photogrammetric mapping and the systematic height error mitigation
Systematic Errors in Road Construction UAS Monitoring

- **Linke & Linke Surveyors** surveyed a road construction site with a UAS at Wagga Wagga (approx. 3km x 300m)

- For quality assurance, RTK check points along road corridor were surveyed

- Point cloud heights are approx. 10cm higher than RTK check string in UAS surveys (3DS X8 drone + Sony QX1 camera with near nadir imaging).

Earthworks are a considerable portion of overall cost to a project - Inaccuracy Costs Money
Systematic errors in cliff photogrammetric survey

James & Robson, Earth Surface Processes and Landforms, 2012
Systematic errors in UAS mapping

Simulated doming effect with nadir images and nadir+oblique images.

James & Robson, Earth Surface Processes and Landforms, 2014
Mitigating systematic error in topographic models
Systematic errors in UAS mapping

“The height error behaves as a function of the distance to the closest GCP.” – doming effect.

Yilmaz, GIM International, 2015
Surveying a 140km Corridor with a UAV for Railway Planning
Error Sources

- Inaccurate lens radial distortion correction
- Unstable camera internal geometries
- Near-parallel image directions
- Error propagation from GCPs

The magnitude of the errors in height (depth) determination caused by the uncorrected radial distortions can be significantly large.

The systematic errors referred to were radial distortion - caused not only by the lens but also by the combined effects of curvature of the earth and the refracting of light rays through the atmosphere.

Fryer and Mitchell: Close-range photogrammetry 1987
Practical Investigations

- DJI Phantom3 Pro Camera (12MP) Nadir images shot with 3-axies gimbal.
- SenseFly eBee + Canon S110 RGB (12MP) Image angle random 0-10° due to wind.
- 3DS X8 +Sony QX1 Camera (20MP) Image angle random 0-10° due to fixed manual mounting, flying speed and wind speed.

- Location: Wagga Wagga - part of road construction site
- 12 GCPs surveyed with RTK
- Vehicle mounted RTK check string survey
Doming Effect in Road Construction Monitoring

Pix4D Mapper generated point cloud vs. RTK check string

CloudCompare software was used to compute height differences between point cloud and RTK check string
Doming Effect in Road Construction Monitoring - Statistical Errors

Phantom 3 + OEM camera

Pitch<2°, Roll<2°
Shutter speeds 1/800”-1/1200”

3DR X8 + Sony QX1 camera

eBee + Canon compact camera
Check point height errors

- Images were processed using Pix4D with 4 GCPs and 8 check points.

- Rescaled check point error plots

Assumption: GCP errors propagate linearly to check points. Rescale the check point height errors and average if multiple points clustered together.

Top view of GCP and CP distribution

<table>
<thead>
<tr>
<th>dH</th>
<th>GCP700</th>
<th>GCP700</th>
<th>GCP715</th>
<th>GCP706</th>
<th>GCP623</th>
<th>GCP704</th>
<th>GCP703</th>
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<td>2</td>
<td>3</td>
<td>4</td>
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Set GCP error = 0

Images were processed using Pix4D with 4 GCPs and 8 check points.
Phantom 3 + OEM camera

eBee + Canon compact camera

3DR X8 + Sony QX1 camera

Height error doming effect between GCPs
Phantom3, H=120m, Nadir

Between 2 GCPs

Height error doming effect between GCPs
eBee, H=120m, off-nadir

Between 2 GCPs

Height error doming effect between GCPs
3DR X8, H=120m, Oblique 15-20°

Between 2 GCPs
Off-Nadir images acquired using eBeeRTK

72 GPs, 6GCPs, off-nadir images (0-15°)

78 CPs, No GCPs, , off-nadir images (0-15°)
Off-Nadir images acquired using eBeeRTK

![Graph showing check point errors with 0 GCPs and 6 GCPs. The graph compares mean x, y, and h values and standard deviations.]

<table>
<thead>
<tr>
<th>check point error</th>
<th>mean</th>
<th>standard deviation</th>
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</tr>
<tr>
<td>0 GCPs</td>
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<tr>
<td>6 GCPs</td>
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<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>h</th>
<th>σx</th>
<th>σy</th>
<th>σz</th>
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<tbody>
<tr>
<td>3.7</td>
<td>5.1</td>
<td>16.5</td>
<td>3.4</td>
<td>2.9</td>
<td>6</td>
</tr>
<tr>
<td>-1.9</td>
<td>-0.2</td>
<td>-0.3</td>
<td>1.9</td>
<td>1.6</td>
<td>4.1</td>
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Summary

For precise UAS photogrammetric mapping:

• Including low oblique images reduces systematic height errors

• Oblique angle 10-15 degrees recommended

• Larger image angles increase GSD and result lower accuracy

• Better quality of cameras or lens can be more precisely calibrated and improve product accuracy

• GCPs provide precise georeferenced products even with RTK image locations.

• Dense GCPs reduce systematic height error and improve accuracy in 3D