Photogrammetric Accuracy and Modeling of Rolling Shutter Cameras

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Rolling Shutter

1. Read 1st “line”

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Rolling Shutter

1. Read 1st “line”  
2. Read 2nd “line”
Rolling Shutter

1. Read 1st “line”  
2. Read 2nd “line”  
3. Read 3rd “line”
Rolling Shutter

“Rolling shutter effect”
Rolling Shutter
Rolling Shutter & UAVs

Global Shutter

\[ x = \pi[R \mid - Rc]X \]

\[ \pi \text{ = internal parameters} \]
\[ R \text{ = Rotation matrix} \]
\[ c \text{ = camera center} \]
Rolling Shutter & UAVs

Global Shutter

Rolling Shutter

Linear motion: camera center depends on time

\[ x = \pi[R | - Rc(t)]X \]
Rolling Shutter & UAVs

Arbitrary motion: camera center and rotation depend on time

\[ x = \pi[R \mid -Rc]X \]

\[ x = \pi[R(t) \mid -R(t)c(t)]X \]
Simplified Model

- We control the flight plan
- Gimbal + rubber correct for vibrations
Simplified Model

Modeling the rolling shutter effect is not new: Ait-Aider et. al. in 2006: “Simultaneous object pose and velocity computation using a single view from a rolling shutter camera”

\[ x = \pi[R | - Rc(t)]X \]

(9 external parameters per image)
Experimental Setup

• Multiple flights at different speeds above Innovation Park:

<table>
<thead>
<tr>
<th>Drone</th>
<th>Camera</th>
<th>Shutter Type</th>
<th>Lens</th>
<th>Field of View [°]</th>
<th>Speeds [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2V+</td>
<td>FC200</td>
<td>Rolling</td>
<td>Fisheye</td>
<td>110/80</td>
<td>1, 4, 8</td>
</tr>
<tr>
<td>Inspire 1</td>
<td>FC300X</td>
<td>Rolling</td>
<td>Perspective</td>
<td>85/70</td>
<td>1, 4, 8</td>
</tr>
<tr>
<td>eBee</td>
<td>Canon S110</td>
<td>Global</td>
<td>Perspective</td>
<td>71/56</td>
<td>8-13</td>
</tr>
</tbody>
</table>
Processing

Calibration

Reoptimize (without rolling shutter)

Reoptimize (with rolling shutter)

Output: displacement vector during the readout
Accuracy

GSD: ~2.8 cm

Global shutter model

Rolling shutter model
Accuracy

![Graph showing accuracy measurements for different wind speeds and drone models.]
Accuracy
Motion Estimation From RS

Blue: From drone’s telemetry
Black: Rolling Shutter model
Readout time estimation

**Inspire 1 (this graph): ~30 ms**
GoPro 4 Black: ~30 ms
Phantom 2: ~80 ms
Reprojection Error

Average reprojection error of all automatic tie points

P2V+ at 8 m/s

Standard fisheye model

Rolling shutter model
Large Dataset
Large Dataset
Large Dataset
Large Dataset

![Graph showing performance of different models under varying wind speeds.](image)
Conclusion

• Rolling shutter effect can be observed in real-life situations
• Simple linear model + flight plan = better accuracy
• Improved usability for consumer drones
• Speed can be estimated based on images only!
Acknowledgements

• Many thanks to senseFly for the eXom and eBee datasets for our tests.
Thank You!
### Accuracy: some numbers

<table>
<thead>
<tr>
<th>Camera model</th>
<th>Speed [m/s]</th>
<th>Reproj error [px]</th>
<th>RMS X [cm]</th>
<th>RMS Y [cm]</th>
<th>RMS Z [cm]</th>
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</thead>
<tbody>
<tr>
<td>P2V+ P2V+ RS</td>
<td>8</td>
<td>0.24</td>
<td>13.5</td>
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<td></td>
<td>0.23</td>
<td>2.3</td>
<td>3.7</td>
<td>1.4</td>
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<tr>
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<td>4</td>
<td>0.24</td>
<td>7.9</td>
<td>8.2</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.24</td>
<td>3.6</td>
<td>2.9</td>
<td>4.6</td>
</tr>
<tr>
<td>P2V+ P2V+ RS</td>
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<td>0.24</td>
<td>1.8</td>
<td>3.6</td>
<td>5.5</td>
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<td>0.24</td>
<td>2.6</td>
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<td>3.2</td>
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<td>1.1</td>
<td>1.7</td>
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<td>16.9</td>
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</tbody>
</table>

GSD: ~2.8 cm