International Conference on Unmanned Aerial Vehicles in Geomatics (UAVg)

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Precise Positioning of UAVs

Dealing with challenging RTK-GPS measurement conditions during automated UAV flights

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High precision mobile mapping applications
- Surveying
- Infrastructural inspection
- Deformation monitoring
- ...

One aim of current research

Fully automated flight and mapping process
- Waypoint / intelligent flight
- Direct georeferencing without user intervention (e.g. target distribution)
- Onboard cm-accurate RTK-GPS solution

Improve of time and cost efficiency
Absolute accuracy of mobile mapping products (e.g. point clouds, orthophotos, etc.) directly depending on quality of onboard RTK-GPS solution

Quality of onboard RTK-GPS solution depends (amongst others) mainly on influences from antenna environment

Site-dependent effects and error sources in GPS positioning
Site-dependent GPS effects

Satellite shadowing (geometry)

Obstruction by buildings or vegetation

waypoint.sensefly.com

www.reconaerialmedia.com
Site-dependent GPS effects

Satellite shadowing (geometry)

Far-field multipath

Direct signal

Reflected signal
Site-dependent GPS effects

Satellite shadowing (geometry)

Far-field multipath

Signal diffraction
Site-dependent GPS effects

Satellite shadowing (geometry)

Non-line-of-sight reception (NLOS)

Signal diffraction

Far-field multipath

Signal diffraction

Direct signal

Reflected signal

Direct signal

Diffracted signal
Site-dependent GPS effects

Satellite shadowing (geometry)

Far-field multipath

Most critical site-dependent effects!

Non-line-of-sight reception (NLOS)

Signal diffraction
Mitigation approaches

Integration of the antenna environment

**a priori**

Forecasting expectable GNSS visibility using digital elevation models

**Mission Planning**

Sky-pointing cameras

**on-the-fly**

Shadow matching and NLOS mitigation using 3D urban city models

**Stand alone GPS applications (pedestrian/car navigation), accuracies at m-level**

NLOS mitigation using Infrared / fish-eye cameras

Gandor et al. (2015)

Lohmar (1999)

Wang et al. (2013)

Meguro et al. (2009)

Moreau et al. (2017)
Proposed approaches

Integration of the antenna environment

GPS Constellation Based Flight Planning

- Generation of ‘geometry maps’ from environment model
- Optimization of waypoint planning by selecting ‘best geometry’
Proposed approaches

Integration of the antenna environment

GPS Constellation Based Flight Planning

1. Generation of ‘geometry maps’ from environment model
2. Optimization of waypoint planning by selecting ‘best geometry’

Obstruction Adaptive Elevation Masks

1. Mitigation of NLOS reception and signal diffraction
2. Determination of epoch wise elevation masks from point clouds
Proposed approaches

Integration of the antenna environment

GPS Constellation Based Flight Planning

1. Generation of ‘geometry maps’ from environment model
2. Mitigation of NLOS reception and signal diffraction
3. Determination of epoch wise elevation masks from point clouds

Integration: on-the-fly

Obstruction Adaptive Elevation Masks

- Generation of ‘geometry maps’ from environment model
- Mitigation of NLOS reception and signal diffraction
- Determination of epoch wise elevation masks from point clouds

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UAV platform and environment

UAV equipped with...
- direct georeferencing unit
- cameras / laser scanner
- processing unit

UAV environment ...
- can be mapped in near real-time during flight
- a priori known from 3D model or point cloud

Developed in DFG Research Unit FOR 1505 – ‘Mapping on Demand (MoD)’
Basic Idea:

Construction of elevation masks that are dynamically adapted to antenna environment

Improved position estimation by mitigating NLOS reception and signal diffraction
Given:

- Point cloud of object
  - A priori environmental model / point cloud
  - derived from the onboard mobile mapping process
- Position $X_R$ and uncertainty $\Sigma_{X_R}$ from initial onboard RTK solution
For every point $i$:

- Determination of azimuth $\alpha_i$ and elevation $\beta_i$ from line-of-sight vector

\[ \alpha_i = \arctan \left( \frac{e_i}{n_i} \right), \quad \beta_i = \arctan \left( \frac{u_i}{\sqrt{e_i^2 + n_i^2}} \right) \]
For every point $i$:

- Allocation to azimuthal grid with predefined cell width
Obstruction Adaptive Elevation Masks

For every cell $c$:

- Identification of highest elevation angle $\bar{\beta}_c$

\[
\bar{\beta}_c = \begin{cases} 
\max \{ \beta_i \in c \} , & \text{cell } c \neq [] \\
0^\circ , & \text{cell } c = [] 
\end{cases}
\]

For every point $i$:

- Allocation to azimuthal grid with predefined cell width
Obstruction Adaptive Elevation Masks

Cell wise adjustment of $\bar{\beta}_c$:

- Propagation of positional uncertainty on determined elevation angles

$$\sigma_{\bar{\beta}_c} = \sqrt{F \cdot \Sigma_X \cdot F^T}$$
Cell wise adjustment of $\bar{\beta}_c$:

$\Rightarrow$ Adding estimated uncertainty to elevation angle $\bar{\beta}_c$

$$\hat{\beta}_c = \bar{\beta}_c + \sigma_{\bar{\beta}_c}$$
Obstruction Adaptive Elevation Masks

OAEM:

> Modification of standard elevation mask by applying determined elevation angles
Usage of GPS antenna on prism pole instead of real UAV

- Measurements in stop&go mode
- Controlled reference measurements with tacheometer and accuracy $\leq 1\text{cm}$

We are aware that...

- Set-Up and measurement procedure do not simulate an UAV flight realistically
- Typical influences, such as vibrations, electromagnetic disturbances or high dynamic motions, not present
Usage of GPS antenna on prism pole instead of real UAV

- Measurements in stop&go mode
- Controlled reference measurements with tacheometer and accuracy ≤ 1cm

- 1-3cm accuracy can be achieved during flight in case of appropriate countermeasures, like e.g. shielding of processing unit (Eling et al. (2015))
- **RTK solution suitable for assessing effectiveness of OAEMs**

We are aware that...

- Set-Up and measurement procedure do not simulate an UAV flight realistically
- Typical influences, such as vibrations, electromagnetic disturbances or high dynamic motions, not present
OAEM – Field Test

- Test measurements

- Point cloud from terrestrial laser scanner

- Negotiation processes

- Precise Positioning of UAVs under challenging RTK conditions

- Approx. 10 m

- Approx. 9 m

- Approx. 2 m
OAEM – Field Test

identified satellites (G23,G30) excluded from position estimation
OAEM – Results

original data set

Up-differences between -18.5cm and 14.3cm
OAEM – Results

original data set

modified data set

... NLOS reception / signal diffraction detected (#21)

Up-differences between -18.5cm and 14.3cm

OAEMs applied

Up-differences between -2.5cm and 2.5cm
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**OAEM – Results**

**Ambiguity solution**

<table>
<thead>
<tr>
<th></th>
<th>Fixed</th>
<th>Float</th>
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</thead>
<tbody>
<tr>
<td>Original data</td>
<td>55%</td>
<td>45%</td>
</tr>
<tr>
<td>Modified data</td>
<td>88%</td>
<td>12%</td>
</tr>
</tbody>
</table>

**Success rate of ambiguity fixing**

Improved by applying *Obstruction Adaptive Elevation Masks*

**Absolute positioning accuracy**

<table>
<thead>
<tr>
<th></th>
<th>East [m]</th>
<th>North [m]</th>
<th>Up [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Original data</td>
<td>0.025</td>
<td>0.036</td>
<td>0.045</td>
</tr>
<tr>
<td>RMS Modified data</td>
<td>0.008</td>
<td>0.007</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Positioning accuracy under challenging RTK conditions can be improved by integrating the antenna environment.

**Initial RTK solution**
Accuracy ≈ 15-20cm

**Improved RTK solution**
Accuracy ≈ 1-3cm

Comparable to ideal measurement conditions!
Open questions...

What are the accuracy requirements for an onboard created environment model?

**Initial RTK solution**
Accuracy \(\approx 15-20\) cm

**Onboard environment model (mobile mapping)**

**Improved RTK solution**
Accuracy \(\approx 1-3\) cm

Mitigation of NLOS reception / signal diffraction
Open questions...

Do we really need an initial RTK solution?

Iterative refinement of OAEM and environment model

Code solution
Accuracy ≈ 2-5m

Onboard environment model (mobile mapping)

Obstruction Adaptive Elevation Mask

Mitigation of NLOS reception / signal diffraction

RTK solution
Accuracy ≈ 15-20cm

final
Obstruction Adaptive Elevation Mask

Improved RTK solution
Accuracy ≈ 1-3cm
Thank you for your attention!

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References


