Photogrammetric Measurement of gravitational deformations of a VGOS antenna using UAV

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VLBI Radio Telescopes...

- Disturbing forces affect radio telescope main reflector
  - Temperature / wind / insolation
  - Snow load / dead load of dish
- Deformations of main reflector impair receiving properties
  - Form stability of surface / stability of focal length
  - ... and variations in time

- VGOS specifications in general
  - More compact design / Faster movements
  - Improved main reflector design (ring-focus paraboloid)
- Accuracy requirements:
  - Residuals of surface < 200 μm (RMS)
  - Signal path variation < 300 μm (RMS)
Close Range Photogrammetry...

Photogrammetric markers for adjusting the panels of the main reflector

- $<< 50 \, \mu m$ for discrete marked points
- Contact-free observation strategy
- Crane for camera positions
Combining Photogrammetry and UAV...

- Unmanned aerial vehicle (UAV, drone)
- Rechargeable batteries
- Remote control via ground-based station
- Consumer camera Sigma DP3 Merrill (with Foveon chip for full color information; weight 380 g)
- gimbal-mount below UAV for camera
- Max. flight time about 25 min
Preparation of VGOS Antenna...

Photogrammetric coded markers

- 72 markers on the surface of the telescope
- 4 markers on the sub-reflector
- 6 calibrated scale bars
- Coordinate cross for preliminary orientation of the images
Preparing Measurement Flights...

Flight plan

- Waypoints of UAV
- Trigger points for camera to take images
- Two circles and two traverses per telescope position
- Altogether ten different elevation positions
- Each elevation position two times
Photogrammetry in Detail ...

Bundle adjustment

- Unique 3D coordinates of object points
- Planar image coordinates of markers
- In situ calibration
- Over 500 connecting points (markers, screws, etc.,) for each elevation position
- Over all uncertainty 80 – 120 µm
- Collinearity equations:

\[
x'_i = x'_0 - c \frac{q_{11}(X_i - X'_0) + q_{21}(Y_i - Y'_0) + q_{31}(Z_i - Z'_0)}{q_{13}(X_i - X'_0) + q_{23}(Y_i - Y'_0) + q_{33}(Z_i - Z'_0)} + \Delta x' \\
y'_i = y'_0 - c \frac{q_{12}(X_i - X'_0) + q_{22}(Y_i - Y'_0) + q_{32}(Z_i - Z'_0)}{q_{13}(X_i - X'_0) + q_{23}(Y_i - Y'_0) + q_{33}(Z_i - Z'_0)} + \Delta y'
\]
Results from Surface Fitting...

Rotational symmetric ring-focus paraboloid in canonical representation

\[ a^2 \left( (x_i - r n_{x,i})^2 + (y_i - r n_{y,i})^2 \right) = z_i \]

- Estimated focal length \( f = \frac{1}{4a^2} \)
- Standard deviation of residuals 200 µm
Budgeting Gravitational Effects...

Signal path variations $\Delta L(\varepsilon)$ by Clark and Thomsen (1988)

$$\Delta L(\varepsilon) = \alpha_F \Delta F(\varepsilon) + 2\alpha_R \Delta R(\varepsilon) + \alpha_V \Delta V(\varepsilon)$$

- Focal length variation $\Delta F(\varepsilon)$
- Displacement of sub-reflector $\Delta R(\varepsilon)$
- Shift of vertex $\Delta V(\varepsilon)$
- Weighting coefficients $\alpha_F, \alpha_V, \alpha_R$
Budgeting Gravitational Effects...

Signal path variations $\Delta L(\epsilon)$ by Clark and Thomsen (1988)

Conclusion...

First investigation of a VGOS-specified VLBI radio telescope

- Proof of feasibility: UAV for photogrammetric survey of a radio telescope surface
  - Less effort than using a crane
  - No further deformations occur due to additional weight

- Determination of signal path variation components due to elevation position
  - Focal length variation of about 2 mm is about ten times smaller than for conventional radio telescopes
  - Displacement of sub-reflector counters focal length variation
Thank you for your attention...
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