Proof-of-Concept Studies for a Local Tie Monitoring System

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Location of Studies: GGAO

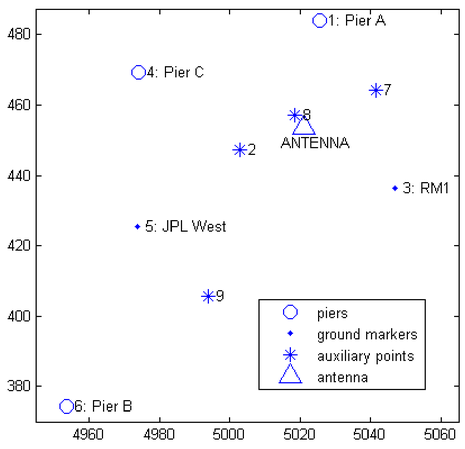
Goddard Geophysical and Astronomical Observatory:
- GGAO co-locates all four geodetic space techniques: VLBI, SLR, GNSS, DORIS
- GGAO has a geodetic network consisting of several piers and ground markers in place
- GGAO has a history of ground surveys and provides most surveying equipment
- The proof-of-concept studies were performed on the VLBI antenna:
  - Results transferable to SLR
  - GNSS and DORIS conceptually easier to be surveyed

Objectives and Requirements

Objectives of the studies:
- monitor the reference point of the VLBI antenna
- monitor the axis offset of the VLBI antenna
- monitor the orientation of azimuth and elevation axes

Requirements for monitoring system:
- positional accuracy < 1mm
- automated operations
- easily extendible to other sensors (e.g., SLR, GNSS)

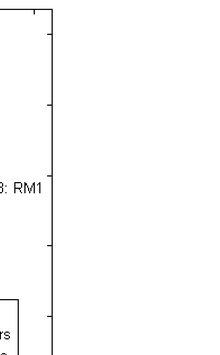
Local network around the VLBI antenna



Survey Equipment

Robotic total station:
- Leica TCA 2003
  - angle measurement accuracy: 0.15 mgon
  - distance measurement accuracy: 1 mm + 1 ppm
  - measurement distance (ATR): 5...500 m
  - measurement time: ~3 sec

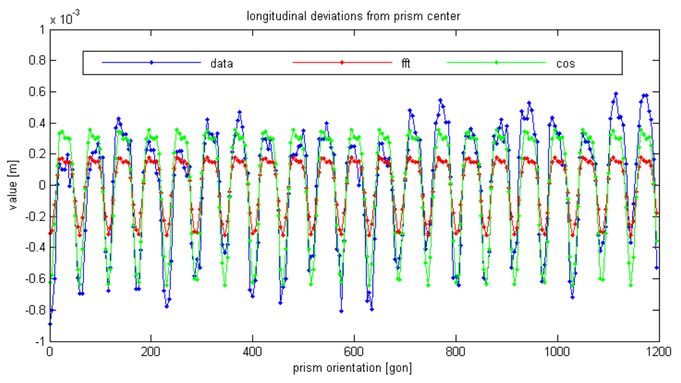
Prisms:
- Trimble 5600 360° prism
- network prisms



Calibration

- Leica TCA 2003:
  - ✓additive constant
- VLBI Antenna Field System:
  - ✓measurement accuracy
- prisms for network points:
  - ✓additive constant
- Trimble 360° prism used as marker
  - ✓additive constant
  - ✓orientation-dependent change of reference point

Calibration of Trimble 360° Prism



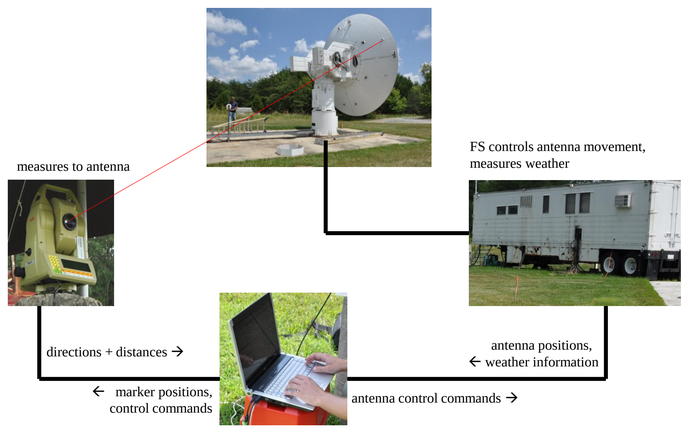
- three full circles (3 x 400 gon)
- seven corner cubes clearly visible
- peak-to-peak variation about 1 mm
- approximations of data with Fourier series and cosine function

Design Aspects of Monitoring System

- Discretization of VLBI antenna movement:
  - ➢ 360° prism marks discrete points at various antenna positions
  - ➢ total station determines prism's movement
- Realization of local reference frame:
  - ➢ coordinates of piers and ground markers define local reference frame
  - ➢ additionally possible: GPS sensors set up on the points
- Control of VLBI antenna (movements/positions):
  - ➢ VLBI Field System (FS) computer
  - ➢ FS executes VLBI antenna movement commands
- Control of robotic total station:
  - ➢ using implemented interface (Lemo-RS232 interface with GSI commands) to laptop
- How to achieve needed accuracy?
  - ➢ calibration of 360° prism's orientation-dependent errors
  - ➢ correct atmospheric influence on total station measurements
  - ➢ eliminate instrument errors using the right measurement procedure

Laptop as control unit for total station and VLBI antenna:

Data flow in the field:



Mathematical Model

Transformation approach (Lösler et al., 2008):
- instead of traditional circle fitting approach
- set of rotations and translations
- describing transformation from antenna-fixed to local coordinate system
- transformation parameters describe antenna characteristics

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = P_R + R_x(\beta) \cdot R_y(\alpha) \cdot R_z(A + O_A) \cdot R_y(\gamma) \cdot \left(\begin{bmatrix} 0 \\ ecc \\ 0 \end{bmatrix} + R_x(E + O_E) \cdot \begin{bmatrix} a \\ b \\ 0 \end{bmatrix} \right)$$

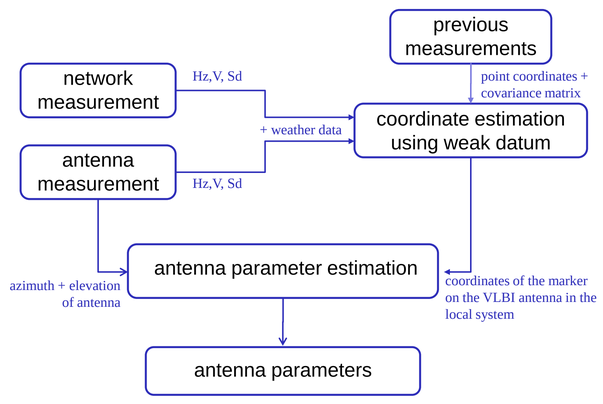
- a,b … marker coordinates in telescope system
- E, O_E … rotation around elevation axis (+orientation)
- ecc … axis offset (eccentricity)
- A, O_A … rotation around Azimuth axis (+orientation)
- P_R … antenna's reference point
- α, β … correction for non-orthogonality of axes
- γ … correction for inclination

Observations:
- Marker positions: x, y, z (by total station)
- Antenna positions: A, E (by Field System)

Parameters:
- "antenna": P_R, ecc, α, β, γ, O_A
- "marker": a, b, O_E

(Ref.: M. Lösler, Reference point determination with a new mathematical model at the 20 m VLBI telescope in Wettzell, Journal of Applied Geodesy, pp. 233-238, 2008.)

Analysis



Simulations

- Antenna measurement simulation settings:
  - σ_{angles} : 0.45 mgon
  - $\sigma_{distances}$: 1.0 mm
  - $\sigma_{FieldSystem}$: 5.0 mdeg
  - σ_{marker} : 0.5 mm
- Two simulations:
  a) using just one instrument position (here: point 4)
  b) using four instrument positions (points 1,3,4,5)

a)

parameter	True error		Formal error		ratio
ref point (x)	0.1489	mm	0.1836	mm	0.81
ref point (y)	0.0797	mm	0.1044	mm	0.76
ref point (z)	0.1387	mm	0.1682	mm	0.82
axis offset	0.1295	mm	0.1629	mm	0.80
alfa	0.0655	mrad	0.0833	mrad	0.79
beta	0.0339	mrad	0.0444	mrad	0.76
gamma	0.1775	mrad	0.2283	mrad	0.78
azim orientation	0.1440	mrad	0.1938	mrad	0.74
a	0.1084	mm	0.1455	mm	0.75
b	0.4638	mm	0.6035	mm	0.77
elev orientation	0.0485	mrad	0.0591	mrad	0.82

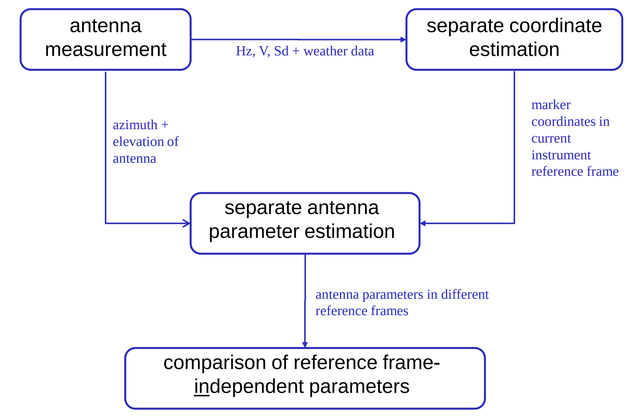
b)

parameter	True error		Formal error		ratio
ref point (x)	0.0402	mm	0.0533	mm	0.73
ref point (y)	0.0409	mm	0.0525	mm	0.79
ref point (z)	0.0625	mm	0.0797	mm	0.78
axis offset	0.0649	mm	0.0764	mm	0.85
alfa	0.0205	mrad	0.0248	mrad	0.83
beta	0.0189	mrad	0.0232	mrad	0.81
gamma	0.0910	mrad	0.1120	mrad	0.81
azim orientation	0.0789	mrad	0.0936	mrad	0.84
a	0.0585	mm	0.0683	mm	0.86
b	0.2533	mm	0.2970	mm	0.85
elev orientation	0.0209	mrad	0.0272	mrad	0.77

Note: True error is the difference between the known value and the estimate for a given parameter.

Preliminary Results

- irregularities in standard analysis results
- reason not found yet: many outliers in measurements?, systematical errors?, software problems?
- ➢ **preliminary results:** comparison of reference-frame independent antenna parameters:
  - axis offset/eccentricity
  - correction angles
  - marker position: a, b, elevation orientation



parameter	deviations from mean & formal errors								unit
	point 1		point 3		point 4		point 5		
axis offset	0.22	0.25	0.36	0.20	-0.14	0.21	-0.43	0.20	mm
alfa	0.12	0.07	0.12	0.08	-0.23	0.10	-0.01	0.09	mdeg
beta	-0.41	0.12	0.33	0.07	-0.20	0.06	0.28	0.08	mdeg
gamma	0.18	0.56	-0.18	0.45	-0.07	0.38	0.07	0.36	mdeg
a	-0.21	0.20	-0.73	0.16	0.30	0.17	0.64	0.17	mm
b	-0.55	1.41	0.28	1.15	0.27	0.98	-0.01	0.94	mm
elev orientation	0.35	0.08	0.49	0.06	-0.21	0.07	-0.63	0.07	mdeg

Conclusions and Future Work

Conclusions:
- automated measurement procedure works
- easy operations / does not need expert surveyors
- projected accuracy meets goals
- some data anomalies need further investigation

Future Work:
- investigate data anomalies
- use several total stations simultaneously
- replace 360° prism with target sphere
- apply the approach to SLR

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