Vertical Deflection Monitoring and Azimuth Control – CCD Geodesy for precise terrestrial Networks

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Abstract: CCD is important in many fields, but Geodesy uses it mainly for Laser tracking. An ideal supplement is Astrogeodesy, e.g. with our mobile zenith camera ZC-G1. It was developed 2001-02 for semiautomatic astropoints of alpine surveys or difficult technical projects. In the next years we'll improve parts of the Austrian geoid by 50 % to ±1-2 cm.

Astro control of polygons and networks raises accuracy and economy remarkably: 2 sun azimuths of ±3" increase both by ~40 %! The additional effort is only 10-20 %; 5^{min} sunshine should do. We plan to use servotheodolites and invite interest groups to cooperate.

Keywords: automatic CCD observation, zenith camera, servo theodolite, GPS nav, PC software, astro-geodesy, sun/star filter, Vertical deflections, geoid, azimuth, network reduction, accuracy, economy.

1. CCD and the Renaissance for Astro-Geodesy

1a) Astrogeodesy had a *Geoid Summit* 1975-90, then a *descent* began: gravimetry, GPS and satellite missions became effective… But 2000 CCD caused a renaissance: chances for automation, software instead of observer's experience, DTMs and local details for satellite geoids.

1b) Additional astro motivation came from a strange effect of alpine Geoids (Austria, Swiss, Croatia): Vertical deflection information is 10-30 times better than gravimetry [Ge.97, Kü.99].

1c) Theoretically known, but forgotten in the last decades: Azimuths increase the accuracy and economy of polygons and networks remarkably, e.g. 5 min sun by >30 % ➔ see chapter 3.

2. New Instruments for Astro-Geodesy

CCD plays an important role in Science and Technique ➔ see ESA or NASA Websites and their impressive *Image galleries* (galaxies, planets..), or new projects in physics and medicine. Against these broad applications, 95 % of CCD geodesy is Laser tracking with only ± 1-3" accuracy.

I show that chances of CCD are also speeding up and achieving higher accuracy by additional use of stars.

In Vienna we construct mobile CCD zenith cameras guided by notebook and GPS, to improve our Geoid by 50 % to 1-2 cm. Automatic astropoints in alpine surveys are optimal to reduce for Vertical deflection (VD effects 2-15 cm/ km) or GPS heights to ±2 cm.

The Zenith Camera ZC-G1 (2001/2, left Fig.) has a Starlite MX sensor (752 x 580 pixels à 11µm) and an objective 5 / 20 cm. Mounted on a special "mini tower" of DurAlu (4 kg) it can be turned exactly by 4 x 90°, even in complete darkness; 20-40 stars give ±0.5-1" accuracy. Usually 2x2 pixels are *binned* for higher sensitivity.

Exposing 4 zenith images takes 5-10 min, a 2nd series controls the results. The spirit levels will be replaced 2003 by digital vertical sensors. For special applications (accuracy < 0.5") a long focus camera G-2 is designed.

1998-2000 we also tested other methods with *external* CCDs: Astrolabe Zeiss Ni2 (±1" in 30 min), Info Tachymeters TCA 1800 (±1-2") and Geotronics [Ge.00]. The time effort depends on the quality of star database and theodolite software. 2003 I plan semiauto CCD tests with Servotheodolites – for polygon or network Azimuths by *Sun or bright Stars* and 4D database (handling ¾ quicker; time series i of star coord. $d_i x_{jk}$ (k = 1..n, j = 1..3). Interested institutes are invited to cooperate, e.g.:

- CCD Servotheodolite: chip tests, sun filters, star error programs, automatic evaluation...
- Zenith camera G-2: higher sensitivity software, market & geoid tests, production series.

Automatic Video methods (Mischke TU Wien 2000) use 2 servotheodolites TM3000 to intersect points/ lines after Förstner. Active targets are found by quick filters, but present CCDs sensitivity is not sufficient for stars. So we'll test the system by manual PC selection – and by sun. Two azimuths of ±3" will increase traverses and networks by 30 % - see next Table.

3. Modern Survey Accuracy – and bad Reduction Models?

Table 3a: The Effect of 1-2 Azimuths in Polygons (Traverses) or Networks

Cross error of an elongated polygon 10x 500 m (± 1 mgon, fixed points No.10, 20), shown at the first 5 points. Errors of 16-19 are symmetric, those with sun Azimuths underlined [Gerstbach 2002].

Polygon	accuracy	each 2 sun azimuths ± 1 mgon				4 Azim.	2-5 Azimuths ± 0.2 mgon		
Point	**a) no Az.**	b) 14,16	c) 13,17	**d) 12,18**	e) 11,19	f)12,14..	g) 11,19	h) 4 Az.	i) 5 alt.
11	±9.2mm	8.8	8.8	**±8.6mm**	<u>7.5</u>	8.3	±<u>6.5</u>mm	7.8	<u>6.3</u>
12	17.2	16.0	15.8	**<u>14.2</u>**	12.6	<u>13.4</u>	9.4	<u>11.6</u>	8.5
13	23.8	21.7	<u>20.0</u>	**17.1**	17.9	16.0	14.4	12.2	<u>11.1</u>
14	28.0	<u>24.8</u>	21.0	**19.5**	21.9	<u>17.9</u>	18.5	<u>13.5</u>	11.4
15	29.5	25.2	21.3	**20.5**	23.3	18.2	20.0	13.1	<u>12.3</u>

We see: azimuths are *useless at center*, but optimal (d) at 25 and 75 % ➔ time effort <u>10 % gives 30 %</u> effect! *"Sun in quarters"* is also optimal when fixpoints have no sightings, for open traverses or small networks. A single <u>Polaris Azimuth</u> can improve a 5-point net by 20 -50 % [Ge.02].

Table 3b: Modern surveys ask for <u>reduction to mm</u> level. Flat areas and leveling are troublefree, but steep sightings (civil eng., alpine projects) are very affected by Vertical deflections. Directions, slant distances (zenith angles) must be VD-corrected, not to loose the accuracy and ellipsoidal relation:

Vertical deflection VD = 20"	Direction red.	Distance red.
Sighting inclined 10 gon (9°)	1 mgon (3.2")	15 mm / km
Steep sighting 50 gon (45°)	6 mgon (20")	69 mm / km

In flat or hilly tectonic areas (basins, Rhine valley, west.Hungary..) VD reaches 15" (5 mgon), in mountains 20-50". GPS requires a high resolution <u>cm-geoid</u> too, which exists only in 2 ‰ of Europe (parts of D, A). A few % have ±3 cm, Western & Central Europe 5 -15 cm.

New satellites (CHAMP, GRACE ..) promise a 1-2cm geoid, but only regional (~150 km) with *no local details* – helpful just for flat areas with easy geology ➔ 90 % of Europe still needs a gravimetric or <u>Astro-geoid</u>. For (1.b) the latter is ~10 times more economical ➔ our small zenith camera G1 is ideal for quick astro profiles, steep valleys, tunnelling control or between high buildings. Additionally VD can be inverted for <u>density</u> structures of the Earth's crust.

Contrary to fixed sites these and other field methods need no high accuracy but quick procedures to get data at many points. CCD speeds up the observation, guided by PC & GPS. For Engineering with polygons or networks, economic methods by Servo theodolites and sun azimuths are forecoming.

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