MOBILE PLATFORM FOR ASTRO-GEODETIC DETERMINATIONS

Octavian BĂDESCU, Assoc. professor – Faculty of Geodesy, Bucharest Technical University of Civil Engineering, octavian.badescu@geodezie.utcb.ro
Alexandru CĂLIN, Assist. professor – Faculty of Geodesy, Bucharest Technical University of Civil Engineering, alexcalin1975@yahoo.com
Paul Daniel DUMITRU, Assist. professor – Faculty of Geodesy, Bucharest Technical University of Civil Engineering, paul.dumitru@gmail.com
Marin PLOPEANU, Assist. professor – Faculty of Geodesy, Bucharest Technical University of Civil Engineering, mplopeanu@yahoo.com
Dan Alin NEDELCU, Dr. Researcher II – Astronomical Institute of the Romanian Academy, nedelcu@astro.ro

***Abstract**: The paper presents some aspects regarding development of an astro-geodetic mobile platform, which will allow geoid determination or geoid validation by astro-geodetic leveling. The scope is to provide real time vertical deviation at a satisfactory precision and low cost by astronomical and geodetic measurements. The mobile platform for astro-geodetic observations consists in a suitable geodetic instrument, CCD micro-camera and GPS time receiver, all these devices as a whole, being controlled by a portable PC. The proposed method includes measurements/observations procedures, data acquisition and adjustment algorithms, instruments and adjacent devices integrated into a platform, automations and results analyses and interpretation.*

***Keywords:** astro-geodetic network, CCD data, vertical deviation, geoid.*

1. Introduction

Beginning with the December 2013, under coordination of the Bucharest Technical University of Civil Engineering (BTUCE), was started a project for new astro-geodetic determinations, in the actual context of technological development. The main scope of the project is to improve the precision and feasibility of astronomical observations by using adequate instruments and improved mathematical algorithms. Although in our country, after 1990 the astro-geodetic determinations was stopped, in many country, most of them European country (Swiss, Germany, Portugal, Holland, Italy, Croatia), astro-geodetic determinations was continued and developed with remarkable results [4], [5], [8], [9], [10]. As we know, Romania has at the end of 90' years a relative dense astro-geodetic network, developed by Military Topographic Direction (MTD) and Military Astronomical Observatory (MAO). Many astro-geodetic determinations were used in combination with gravimetric determinations, resulting an astro-gravimetric network, which represented the base of the first astro-gravimetric geoid over the national territory [3].

Always astro-geodetic determinations were expensive and time consuming, implying numerous personals as well as difficult and elaborated methods for observations. One of the difficulties was uncertainties induced by the operator, as a consequence of the visual observations. Regarding classical observation methods we mention that only stars situated in particular positions on the sky, could be observed, which meant planning observation sessions [3].

2. Astro-geodetic vertical deviation

How the geocentric coordinates are determined respect to the Earth's center, the geodetic coordinates respect to the reference ellipsoid, the astronomical coordinates are determined respect to the local vertical from observation's point. Vertical's deviation is usually decomposed in two orthogonal components: one component on the north-south direction (ξ) and an east-west or prime vertical component (η). The relations between astronomical coordinates and geodetic coordinates are:

$$\xi = \Phi - B, \qquad \eta = (\Lambda - L)\cdot\cos B \tag{1}$$

The next relation, on the base of these two components, gives the total vertical's deviation:

$$\varepsilon^2 = \xi^2 + \eta^2 \tag{2}$$

The vertical's deviation on some azimuthally direction (α) is:

$$\varepsilon_\alpha = \xi\cdot\cos\alpha + \eta\cdot\sin\alpha \tag{3}$$

that is a well-knowing relation in geodetic calculations.

The vertical's deviation can be defined at the geoid or at the ellipsoid. The vertical's deviation at the geoid, after Pizzetti (ε_G) is the angular difference between the direction of the gravity vector and the normal of the ellipsoid in the one and the same point situate on the geoid. The vertical's deviation on the Earth's surface (topographical surface), after Helmert (ε_P) is the angular difference between the direction of the gravity's vector and the normal on the ellipsoid in the one and the same point [1], [2].

3. Instruments

The main target of the project is to develop a mobile and automate platform for astronomical measurements for astro-geodetic determinations. For precision and feasibility improving of the astro-geodetic determinations we follow up to develop a new method by elaboration of an adequate mathematical algorithm for data acquisition and adjustment, designed for current geodetic instruments. For avoidance the visual observations (personal operator errors) we are designing a micro-CCD image acquisition system synchronized by a GPS time receiver. Thus, star images together with the image of the total station reticular wires, will be taken at precise time interval. During the observations session reticular wires will be illuminated at an adequate intensity, according as sky quality and adjacent area illumination conditions. For alignment the micro-CCD image acquisition system with the optical system of the total stations (translation and/or rotation) there are several solutions. We work at a solution based on the position of virtual (software) reticular wires on the micro-CCD array, comparative with total station reticular wires, the last ones considered adjusted. Therefore, the assembly formed by micro-CCD camera and the GPS time receiver, have to remove de personal operator errors, observations becoming impersonal. During observations, both micro-CCD camera and GPS time receiver will be controlled and monitored with a laptop, via IEEE1394B respectively USB2.0 ports. All stars images together with de time required for each image will be archived on the laptop solid state drive (Figure 1).

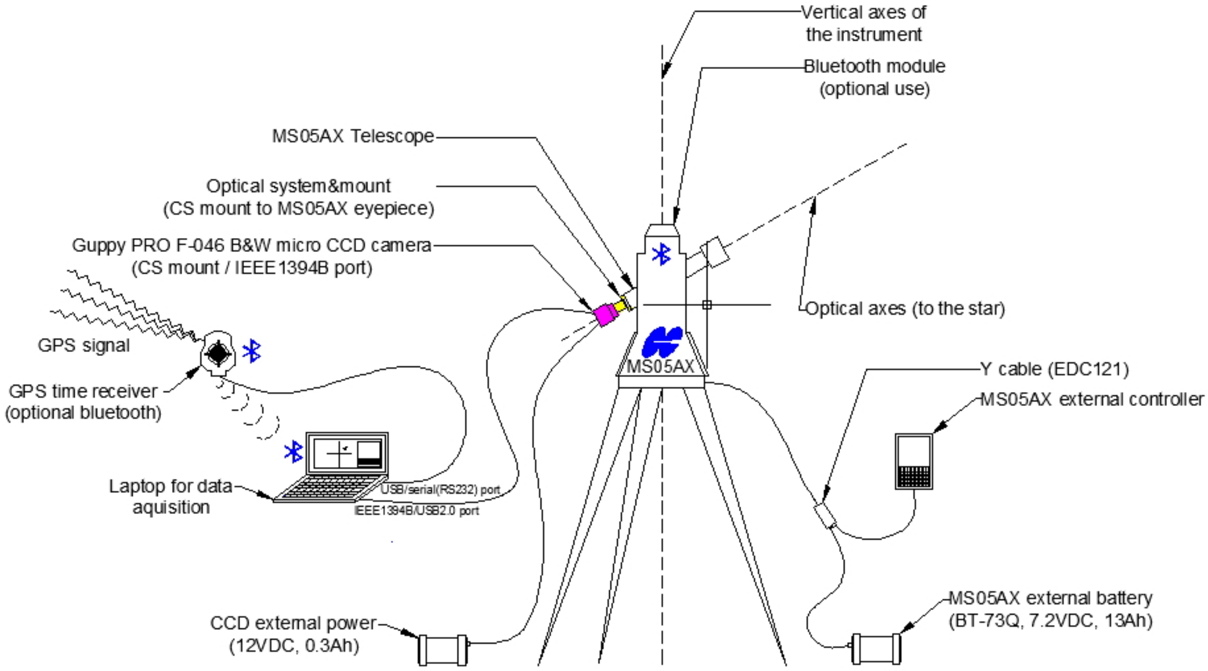


Fig. 1. The astro-geodetic platform draft.

Practically, the astro-geodetic platform will be composed by 2 unify systems but independently controlled: the *angular measuring system* formed by the total station monitored with the external controller and the *data acquisition system* formed by micro-CCD electro-optical system and the GPS time receiver, controlled by the laptop (Figure 1, Figure 2).

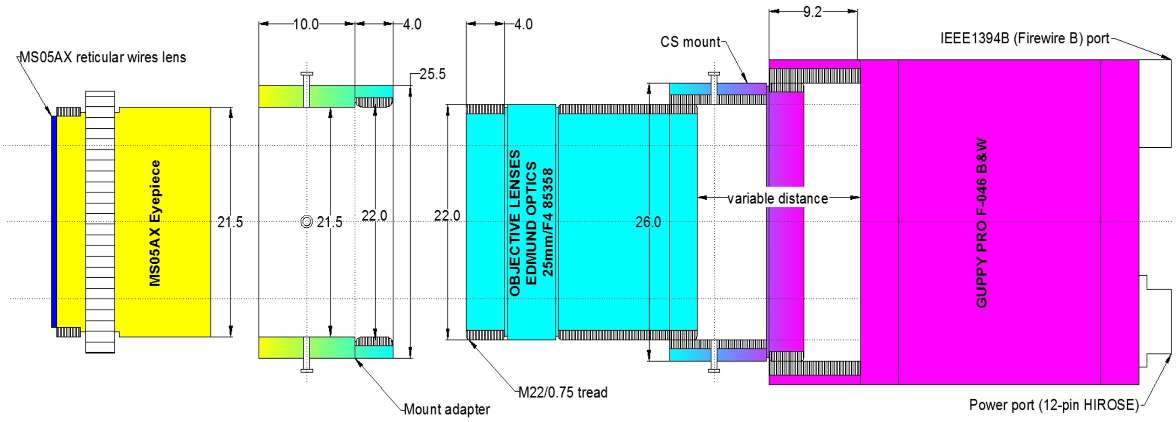


Fig. 2. Data acquisition system (micro CCD camera, optics and mounts) of the astro-geodetic mobile platform.

One important stage of the project is testing the new method. Always, as a general rule in measurements technique, implementation of a new method assumed comparisons with other methods, which use different measurement principles and instruments.

The instruments used for the mobile platform realization are: 1) a geodetic high class precision total station Topcon MS05AX, 2) two GNSS geodetic systems, 3) a CCD micro-camera with some additional lenses, 4) one GPS systems for time measurements and 5) a laptop for terrain data acquisition, control and monitoring of the equipment and preliminary data adjustment. Some technical data for principal instruments implied in the angular measuring system and data acquisition system are showed in the Table 1 and Table 2. All equipment was chosen after a careful analysis regarding technical characteristics, the price-quality ratio and the maintenance service.

Table 1. Technical characteristics of the geodetic instrument.

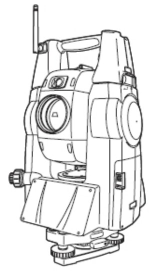
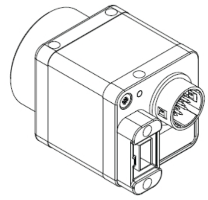
Topcon MS05AX geodetic total station		
Telescope	Length	168 mm
	Aperture	45 mm
	Magnification	30X
	Image	Erect
	Resolving power	2".5
	Field of view	$1^{o}30'$ (26m/1000m)
	Reticle illumination	5 brightness levels
Angle measurement	Horizontal and Vertical circles type	Rotary absolute encoder scanning
	Independent Angle Calibration System (IACS)	Yes
	Minimum display	0".1 (0.00002gon)/ 0".5 (0.0001gon) selectable
	Accuracy (ISO 17123-3:2001)	0".5 (0.00015gon/0.0025mil)
	Collimation compensation	On/Off (selectable)
Tilt angle compensation	Type	Liquid 2-axis tilt sensor
	Range of compensation	±4'
	Automatic compensator	ON (V&H/V)/OFF (selectable)
	Compensation constant	Can be changed
Motor	Type	DC motor drive
	Motion range	360^{o} (Vertical and horizontal)
	Rotation speed	60^{o}/sec (at 20^{o}C)
	Fine motion	Jog dials
General	Operating system	Windows CE Ver. 5.0
	Display	Backlight 0 to 8/Auto (selectable)
		Resistance-sensitive analog type
	Keyboard	32 keys face I & face II, backlight
	Sensitivity of levels	Plate level: 20"/2mm Circular level: 10'/2mm

Table 2. Technical characteristics of the micro CCD camera.

Guppy Pro F-046 B&W micro CCD camera	
Image device	Type 1/2 (diag. 8 mm) progressive scan SONY IT CCD ICX415AL/AQ with HAD micro-lens
Effective chip size	7.48 mm x 6.15 mm
Cell size	8.3 µm x 8.3 µm
Picture size (max.)	780 x 580 pixels (Format_7 Mode_0)
Lens mount	Adjustable C-Mount: 17.526 mm (in air); Ø25.4 mm; maximum protrusion: 10.1 mm
ADC	14 bits
Frame rates	1.875 fps; 3.75 fps; 7.5 fps; 15 fps; 30 fps; 60 fps. Up to 62 fps in Format_7
Gain control	Manual: 0-24.4 dB (0.0359 dB/step); auto gain (select. AOI)
Shutter speed	31 µs … 67,108,864 µs (~ 67 s); auto shutter (select. AOI)
Digital interface	IEEE 1394b (IIDC V1.31), 1 x copper connector
Power requirements	DC 8 V - 36 V via IEEE 1394 cable or 12-pin HIROSE
Power consumption	Typical < 3.5 watt (@ 12 V DC) (full resolution and maximal frame rates)
Dimensions	44.8 mm x 29 mm x 29 mm (L x W x H); incl. connectors, without tripod and lens
Mass	75 g (without lens) + 5 g filter ring

4. The astro-geodetic network

The main activities during the year 2014 are the realization of the astro-geodetic network: network design and materialization, as well as geodetic observations: GPS and levelling measurements. The final astro-geodetic network will be composed by approximate 20 points, over the Bucharest metropolitan area and Ilfov County. Designing of the astro-geodetic network respect some principles, as well: 1) the astro-geodetic point have to be placed in dark zones, far away of the light sources as street illumination and away from possible vibration, as streets traffic, 2) the astro-geodetic point have to be placed as close as is possible from benchmarks (reference points) with knowing coordinates: WGS84/ETRS89 latitude (B) and longitude (L), ellipsoidal (h) and normal/orthometric (H) height. In some cases, if one benchmark is suitable for astro-geodetic observations, the astro-geodetic point will be exactly the same with the benchmark, 3) the astro-geodetic points of the network will be doubled, at a reasonable distance each other, avoiding the risk of extinction, 4) the distance between two adiacent astro-geodetic point will be approximately half of the distance accepted for plane areas, respectively under 10 km.

Also, the astro-geodetic network will contain 5 special points, in which will be realized both visual and CCD observations, for method testing and adjusting. The main reasons for choosing these locations are either the existence of previous astro-geodetic data or some characteristics as position or stability: 1) pilaster on the roof of BTUCE Faculty of

Geodesy (FG), where was executed several visual astro-geodetic determinations (2001-2002, 2012, 2014), placed near to the BUCU (A class) reference station (Figure 5), 2) astrolabe pilaster of the Astronomical Institute of the Romanian Academy (AIRA) where during 1998-2000 was executed astro-geodetic CCD determinations with the Danjon astrolabe and during 2000-2002 visual astro-geodetic determinations with Leica TC2002 total station (Figure 4), 3) Military Astronomical Observatory (MAO) where de fundamental point Dealul Piscului is known as Laplace point, 4) a new and very stable ground pilaster in the mid-quarter Colentina (back yard of the BTUCE Hydro Technical Laboratories (HTL)), without previous astro-geodetic determinations, not really good for astro-geodetic observations, but which will permit an adequate calibration of the CCD image acquisition in real illumination condition, city specific (Figure 3) and 5) point inside of the Mogosesti village area, the southernmost point of the network, without known coordinates and without pilaster materialization, but into a good location for astro-geodetic determination. In this point, the geodetic instrument will be placed on the tripod for the sinking evaluation and will be used mainly for extrapolation study, being outside of the main work area.

Fig. 3. The new ground pilaster from mid-quarter Colentina (BTUCE-HTL), Bucharest metropolitan area (year 2014).

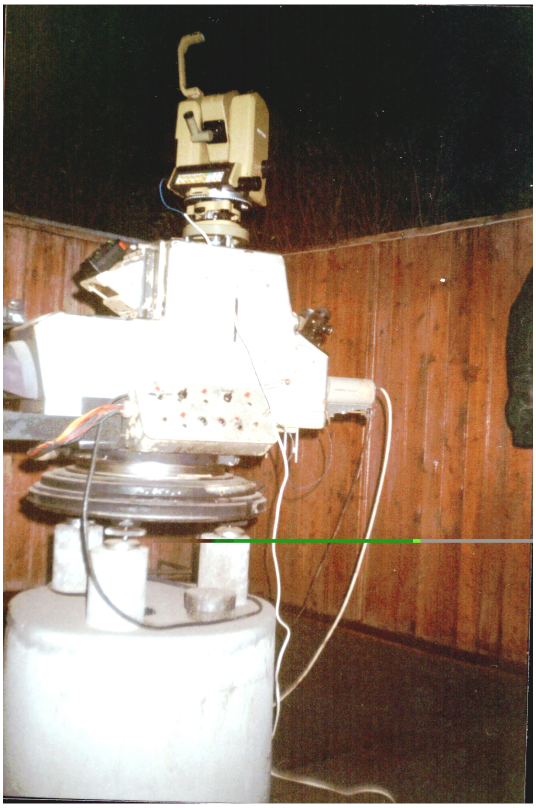


Fig. 4. Astrolabe pilaster of the Astronomical Institute of the Romanian Academy. Coaxial with the astrolabe, Leica TC2002 total station, during astro-geodetic determinations (year 2000).

From approximate 100 known points (benchmarks / reference points) with geodetic coordinates (WGS84/ETRS89 B, L, and h, H) was selected 30 points with adequate surrounding area for astro-geodetic determinations in accordance with principles already listed. From these, 5 were considered insecure and abandoned. At the remaining 25 points were added the special 5 points above described. Almost all 30 points were visited during nighttime for surrounding area evaluation from astronomical observation point of view. Until now, was completed over 500 km for daytime and nighttime recognition.

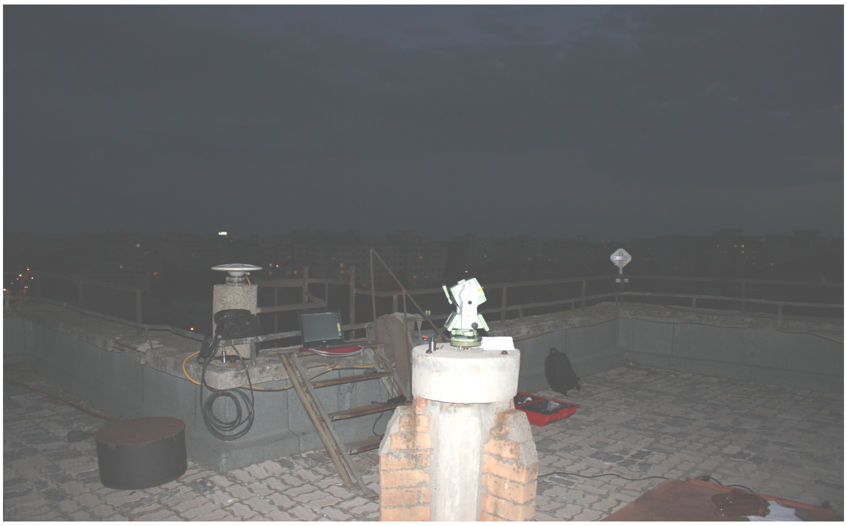


Fig. 5. Pilaster on the roof of BTUCE Faculty of Geodesy,
and Leica TCRP 1201+ during astro-geodetic determinations (year 2012).

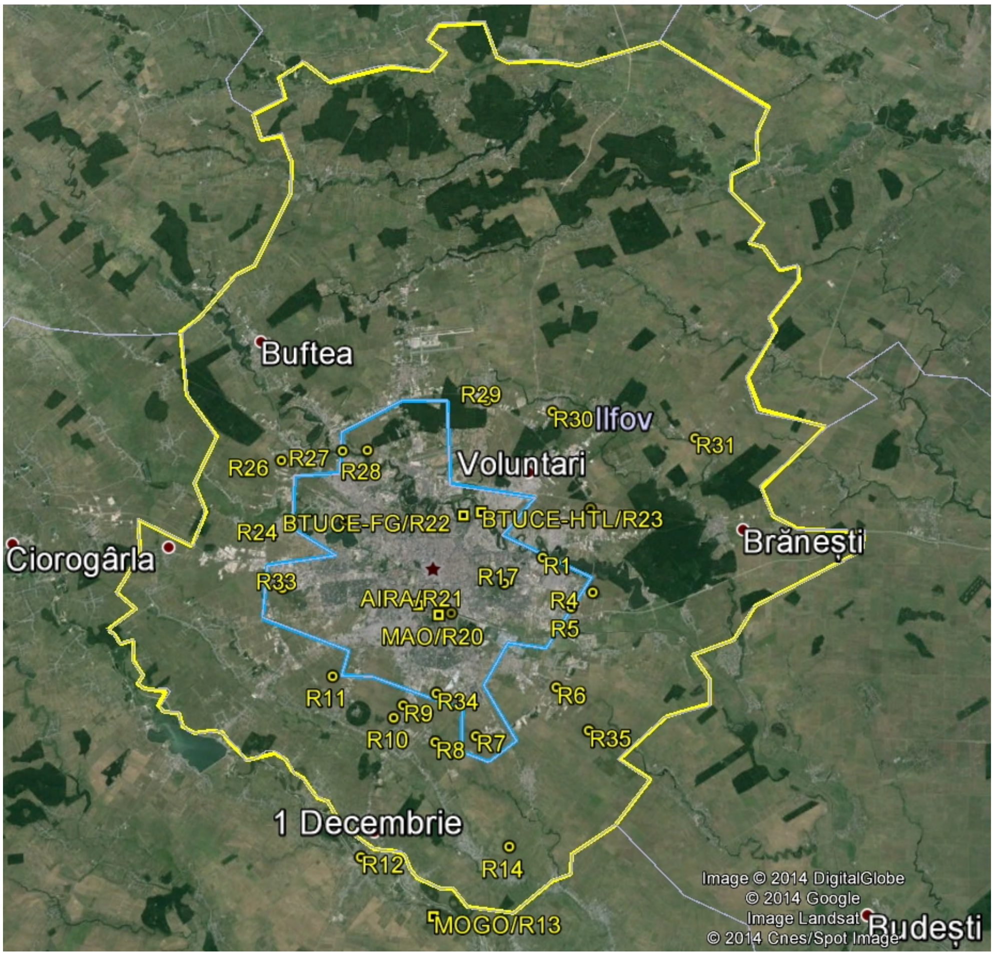


Fig. 6. Benchmark points for astro-geodetic network realization
(Google Earth ver. 7.1.2.2041).

Figure 6 show the reference points positions (25 benchmark plus 5 special points). In the vicinity of the benchmark will be located astro-geodetic points (not represented in Fig. 6) or, for a limited number of benchmarks, astro-geodetic points are the same with those. Square symbol (◘) represents points considered for both visual and CCD astro-geodetic determinations. The circular symbol (◘) represents points considered only for CCD observations. For all astro-geodetic points will be realized GPS and levelling measurements, the last ones run up from benchmarks. All astro-geodetic points will be materialized by a special metallic landmark, designed and constructed at BTUCE-FG.

Acknowledgements. *This work was supported by a grant of the Romanian National Authority for Scientific Research, Program for research - Space Technology and Advanced Research - STAR, project number 216. The authors also thank the National Centre for Mapping for the provided support.*

5. References

1. *Rüeger J.M., Featherstone W.E., The importance of using deviations of the vertical for the reduction of survey data to a geocentric datum, http://www.cage.curtin.edu.au/~will/Devertfinal.pdf*
2. *Featherstone W.E., The importance of including the geoid in terrestrial survey data reduction to the Geocentric Datum of Australia, http://www.cage.curtin.edu.au/~will/Featherstone_TAS_42_1_45-50.pdf*
3. *Rotaru M., Anculete Gh., Paraschiva I., Evoluţia concepţiei geodezice militare în România, D.T.M., Bucureşti, 1989*
4. *Bürki B., Zenith camera and determination of deflections of the vertical (in Switzerland), https://www.rdb.ethz.ch/projects/project_pdf.php?proj_id=6106*
5. *Christian Hirt, Bürki B., The Digital Zenith Camera - A New High-Precision and Economic Astrogeodetic Observation System for Real-Time Measurement of Vertical Deflections, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.113.7413&rep=rep1&type=pdf*
6. *Popescu P., Popescu R., Paraschiv P., The single image modernized astrolabe of Bucharest Observatory, Romanian Astronomical Journal, Vol. 7(2), 189, 1997*
7. *Popescu R., Paraschiv P., Processing of CCD Astrometric observations with the Bucharest Astrolabe, Publications of the Astronomical Observatory of Belgrade, No.60, 110-113, 1998*
8. *Voigt C., Denker H., Hirt C., Regional Astrogeodetic Validation of GPS/Levelling Data and Quasigeoid Models, International Association of Geodesy Symposia, 1, Volume 133, Observing our Changing Earth, Part 2, 2008, Pages 413-420*
9. *Hirt C., Bürki, B., Somieski, A., Seeber, G., Modern Determination of vertical deflections using digital zenith cameras, Journal Surveying Engineering 136(1), 2010*
10. *Hirt C., Reese B., High-Precision Astrogeodetic Determination of a Local Geoid Profile Using the Digital Zenith Camera System TZK2-D, Electronic Proc. IAG GGSM2004 IAG International Symposium Porto, Portugal, 2004*