MOBILE PLATFORM FOR NEW ASTRO-GEODETIC OBSERVATIONS

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Abstract. The paper presents some results obtained for the design, development and testing a mobile platform for astro-geodetic determinations, capable to provide vertical deviation at a satisfactory precision and low cost. Implementation of this platform involves solving technical problems and development of appropriate algorithms lead to increased accuracy and efficiency of astro-geodetic observations. Astro-geodetic method of determining vertical deviation can be more effective for local accurate geoid determination than other methods, if become more accurate, less time consuming and cheaper.

Key words: astrometry – geodesy – CCD observations – vertical deviation.

1. INTRODUCTION

Astro-geodetic observations represent the combination of two different approaches regarding positioning on the Earth surface. Astronomical observations basically mean ground astrometry with adequate instruments for as precise and accurate as possible determination of the observation point position on the Earth's topographical surface. The result of astronomical observations is the latitude Φ and longitude Λ, called astronomical coordinates, in accordance with the name of the determination method. The second approach for positioning is by geodetic techniques which provide, for the same point on the Earth's surface the second coordinates set called geodetic latitude ϕ and longitude λ. The geodetic positioning implies either geodetic terrestrial measurements or satellite/ GNSS (Global Navigation Satellite System) determinations. So, in the same point on the Earth's surface we have two different coordinates' pairs. The difference between the two sets of coordinates come from their definitions: astronomical coordinates are referred to the local vertical or local plumb line while geodetic coordinates are referred to the normal of the reference ellipsoid, both directions passing through the same point on the Earth's surface. As is known, the local vertical is normal to the geoid the physical figure of the Earth, while the ellipsoid represent the geometrical figure of the Earth, with an easy mathematical description and which, theoretically, approximates as good as possible the geoid.

The local vertical is directed to excess mass inside the Earth and practically represent the direction of the gravity vector. The geoid closely approximates the mean sea level in the absence of disturbing forces as winds, ocean currents and tides. Therefore, the geoid is a close figure, on which permanently, the local verticals are normal. The mutual position of the two normal give us the geoid-ellipsoid reciprocal position (Hofmann-Wellenhof and Moritz, 2006).

2. THE VERTICAL DEVIATION AND THE GEOID

The deviation of the vertical is the angular difference between the direction of the gravity vector (local vertical or plumb line) and the normal on the ellipsoid in the same point. Depending on where the vertical deviation is determined or calculated, we have two definitions: 1) Helmert* definition, ϵ_T: angular difference between local vertical (direction of the gravity vector) and normal to the ellipsoid, in the same point on the Earth's topographical surface 2) Pizetti† definition, ϵ_G: angular difference between the direction of the gravity vector (local vertical) and the normal of the ellipsoid in the one and the same point on the geoid.

For any of the two definitions, the deviation of the vertical is usually decomposed in two orthogonal components: ξ one component on the north-south direction, that is, a meridian component, positive towards the north, and an east-west or prime vertical component eta, positive to the east. The relations between astronomical coordinates and geodetic coordinates which gave the vertical deviation components are:,

$$\xi = \Phi - \phi, \eta = (\Lambda - \lambda)\cos\phi \tag{1}$$

The following relation, based on these two components, provides the total deviation of the vertical:

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

The deviation of the vertical on some azimuthal direction (α) is:

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

The vertical deviation reflects the un-parallelism between the geoid surface and the reference ellipsoid surface. Anomalies in the variation of the respective differences from point to point will be the direct consequence of the anomalies in the masses distribution in the terrestrial crust in the given zone. This happens because

*Friedrich Robert Helmert (1843 1917), German geodesist and an important writer on the theory of errors.

†Paolo Pizzetti (1860 1918), Italian geodesist, astronomer, geophysicist and mathematician.

the deviation of the vertical (plumb line) is produced by the excess of masses (Rüeger and Featherstone, 2000; Hofmann-Wellenhof and Moritz, 2006).

The vertical deviation at geoid surface, in general, is not equal with vertical deviation at Earth's surface. For linking these two quantities it is necessary to know the curvature of the local vertical (or more exactly the deflection caused by the curvature, named in scientific literature vertical deflection) between geoid and topographical Earth's surface. Unfortunately, the deflection cannot be observed because of terrestrial masses, it can be only estimated at a low accuracy level:

$$\Delta\epsilon = \Delta\xi = 0''.17 \sin 2\phi\, H, \tag{4}$$

where $\Delta\epsilon$ represents the difference between vertical deviations in Pizzeti and Helmert definition, i.e. difference between vertical deviation on the geoid minus vertical deviation at the Earths surface. Relation 1 shows that only meridian component of the vertical deviation $\Delta\xi$ is affected, and H is the orthometric height taken in kilometers (Rüeger and Featherstone, 2000; Hofmann-Wellenhof and Moritz, 2006).

Another quantity involved in the geoid determination is the geoidellipsoid separation, N (also named geoid undulation) which represents the distance along the vertical (or plumb line) between geoid and ellipsoid. The separation can be obtained by gravimetric measurements, combined GNSS observations with geodetic levelling or from gravity potential coefficients determined by satellite measurements (Featherstone W.E., 1997; Rüeger and Featherstone, 2000; Hofmann-Wellenhof and Moritz, 2006).

Knowing the geoid-ellipsoid separations it is possible to derive vertical deviations at the geoid surface, which is relatively useless since the almost all terrestrial measurements (except spatial distances) are realized towards local vertical at the Earth's topographic surface. Inverse, knowing vertical deviation and its components is possible to calculate N by astro-geodetic levelling if it is known the separation at least one astro-geodetic point and if there is an adequate density of the astro-geodetic points for admitting a linear variation of the vertical deviation between points: 1 point at 10-20 km for flat areas and 1 point at 3-5 kilometers for rugged areas. It is important to remark that only technique which directly provides vertical deviation at the Earth's surface is the astro-geodetic method (Featherstone W.E., 1997; Rüeger and Featherstone, 2000; Hofmann-Wellenhof and Moritz, 2006).

Satellite missions as CHAMP (CHAllenging Minisatellite Payload, German Research Centre for Geosciences), GRACE (Gravity Recover and Climate Experiment, National Aeronautics and Space Administration), GOCE (Gravity field and steady-state Ocean Circulation Explorer, European Space Agency) or provide global longwave global geoid models (smooth surfaces) which mainly serve as reference for a better global or zonal geoid model. Thus, a combination between satellite derived models and regional data from terrestrial measurements is the suitable solution for obtaining a high resolution geoid. Terrestrial methods as the astro-geodetic one are able to detect short wavelength structures of the geoid beside gravimetric, GNSS and levelling. All this terrestrial methods have both advantages and disadvantages, general rules being their use in various combination (Featherstone W.E., 1997; Hirt and Reese, 2004; Hofmann-Wellenhof and Moritz, 2006)

3. ASTRO-GEODETIC OBSERVATIONS IN THE PRESENT CONTEXT

Classical astro-geodetic observations were characterized by several inconveniences, both practical and theoretical, among which we can mention (Rotaru *et al.*, 1989): 1) only certain stars located in specific positions could be observed in accordance with the methodology adopted, which means ephemeris calculation before conducting observations; 2) most observations were zenithal measurements, affected by astronomical refraction, being almost ignored azimuthal measurements; 3) use of different methods for determining separate astronomical longitude and latitude, leading to inconsistent results; 4) very long time to perform observations with consequent high costs; 5) Using special instruments, difficult to handle, expensive and no efficiency (universal theodolites, passage instruments, astrolabe);

For the above reasons, for a long time, astro-geodetic observations have been avoided. But in the last decade, the astro-geodetic method back into focus for at least three reasons: a) the development of the CCD technology which, to a large extent, allowed the elimination of inherent human error, bringing a substantial accuracy and efficiency increase; b) the development of new astronomical or geodetic instruments; c) portable computers and software able to take the entire astrometric calculations, since the field.

In our country, we have over 100 year (1859-1999) of astro-geodetic determinations mainly realized by Topographical Military Directorate (TMD) and Military Astronomical Observatory (MAO, Figure 1). Most and relevant determinations was performed in the 1965-1975 decade, resulting over the whole national territory 146 Laplace points (points with complete astro-geodetic determination: astronomical latitude, longitude and azimuth) and 118 astro-gravimetric points (points with determinations of astronomical latitude, longitude and gravimetric determinations).

These astro-gravimetric determinations were the basis of the first geoid model over the national territory. Regarding the astronomical measurements, it should be noted that for a single Laplace point were required 24 nights of observations and for a single astro-gravimetric point were required 18 nights of observations. Reported precision of these measurements was of $\pm 0''.30$ for Φ, $\pm 0''.45$ for Λ and $\pm 0''.50$ for the astronomical azimuth A (Rotaru *et al.*, 1989). Today, these values seems to

Fig. 1 – Commemorative plaque on West Meridian Pilaster (MAO), built in 1895 where the same year held t he first determinations of astronomical latitude and in 1900 the first determination of astronomical longitude. Today the pilaster represents the fundamental geodetic point of the national geodetic network

be quite optimistic, but we have to take into account the methodology used at the time to achieve both measurements and their processing. However, the situation in our country is similar to that of most countries, relatively few in number, who were able to realize such astro-geodetic networks. Following a protocol of cooperation between Technical University of Civil Engineering Bucharest Faculty of Geodesy (TUCEB-FG) and TMD, were found in the MAO database a huge number of determinations (over 3000 points with astronomical latitude and longitude determinations which cover the national territory), apparently unused until now. Thus, it has started a study on the recovery and validation of these determinations of great historical and scientific value.

4. FIRST LABORATORY TEST FOR NEW ASTRO-GEODETIC OBSERVATIONS

As already mentioned, currently, CCD technology become a key element in the astro-geodetic determinations. In the last decade, significant results were obtained by developing new instruments for astro-geodetic determinations, mostly based on zenithal cameras (former photographic zenithal tubes). These instruments have more features, among which we can mention: do not need horizontal orientation, astronomical refraction has little influence near the zenith and are transportable (Hirt and Bürki, 2003; Hirt and Reese, 2004; Hirt *et al.*, 2010; Bürki , 2014).

In our country, in the interval 1998-2013, was performed only two studies regarding astro-geodetic determinations. The first one was realized at Astronomical Institute of the Romanian Academy Bucharest Observatory (AIRA-BO), where in the interval 1998-2000, was performed first CCD observations for vertical deviation determination with the modernized Danjon astrolabe. Although the used astrolabe is not a transportable instrument, for the first time in our country, a CCD camera and a time signal capturing motherboard, was used for astrometric observations (Popescu *et al.*, 1997; Popescu and Paraschiv, 1998). The second study was undertaken at TUCEB-FG, mainly for creating a new algorithm for astro-geodetic determinations used in combination with modern geodetic instruments. Observations were visually made, with a Leica TC2002 total station gifted by bent eyepiece, together with an electronic chronometer for time measurement. After instrument calibration according with manufacturer indications, 5 observations nights were performed at BTUCE-FG pilaster situated on the roof building. Another 4 observations nights were performed at AIRA Danjon astrolabe, where the total station was set coaxially with the astrolabe, for the comparative analysis between the two methods.

Beginning with the December 2013, under coordination of the TUCEB-FG, 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. Also, the second scope is to verify and validate global geoid models currently available, on the national territory, by using vertical deviation calculated from models and vertical deviations calculated from astro-geodetic observations.

For these reasons, TUCEB-FG in cooperation with AIRA-BO and Geogis Project S.R.L., as private co-financing partner, began building a mobile platform designed for new motorized geodetic instruments electronically total stations or electronically theodolites. The mobile platform project practically consists in four devices that have to work together, as follows:

1. An motorized electronically total station Topcon MS05AX (168 mm telescope length, 45 mm telescope aperture, 30 telescope magnification, minimum angular value displayed, angular accuracy) with tilt angle compensator and 5 brightness levels for reticle illumination;

2. A micro-CCD camera, Guppy Pro F-046 B&W (type 1/2, diag. 8 mm) progressive scan SONY IT CCD ICX415AL/AQ with HAD micro-lens, 7.48×6.15 mm effective chip size, cell size 8.3 8.3 μm, 14 bits ADC, 0-24.4 dB (0.0359 dB/step) manual gain control / auto gain; 1.875 fps/3.75 fps/ 7.5 fps/15 fps/30 fps/60 fps/up to 62 fps in Format7, IEEE1394b interface, 44.8 mm x 29 mm x 29 mm (L x W x H) dimensions, 75 g (without lens) + 5 g filter ring mass;

3. A GPS time receiver;

4. A portable computer for data acquisition (images, time measurements and angular measurements), equipment's control and monitoring and preliminary data adjustment.

The first technical problem that had to be solved was to find a solution for attaching the micro-CCD camera to the optical system of the Topcon MS05AX through a micro objective (Edmund Optics EO 25 mm/F4) so that the images also contain the reticular wires. Initially, the mount prototype was handcrafted, by plastic (Figure 2), then made lathe by bronze (Figure 3) and aluminum.

After these tests was realized final project of the mount (Figure 4), which is made by Polyamide/Duramid (Figure 5). The mount shape, size and weight play an important role in automation observations in both faces of the instruments telescope.

Fig. 2 – The handcrafted mount prototype, made of plastic.

The first test images, daytime obtained in laboratory, with the AVT Vimba Viewer software, contain both target and crosshairs (Figures 6, 7 and 8).

Soon we will run the first night test, taking images of stars. The reticular wires will be illuminated at an adequate intensity of the 5 brightness levels of the Topcon MS05AX. It also will test the synchronization of images respectively taking pictures at precise moments in time. This will be achieved by means of a satellite time signals receiver developed at AIRA-BO.

Fig. 3 – The machined bronze prototype.

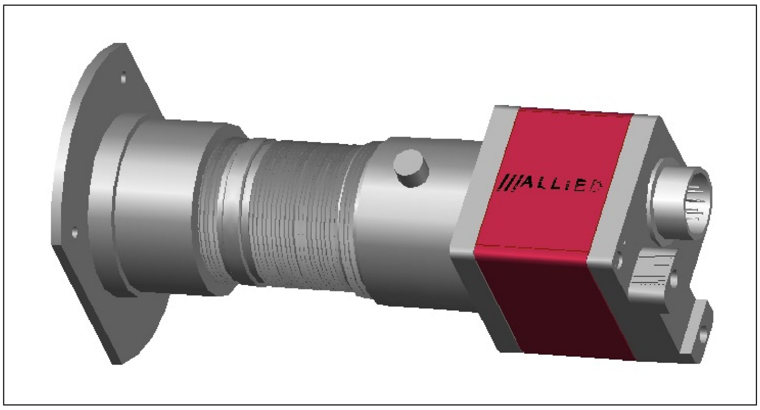

Fig. 4 – The 3D project of the mount that couples the CCD micro-camera to the optical system of the total station.

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Fig. 5 – The realized mount made by Duramid (left), the EO micro-objective (center) and micro-CCD camera Guppy Pro F-046 (right).

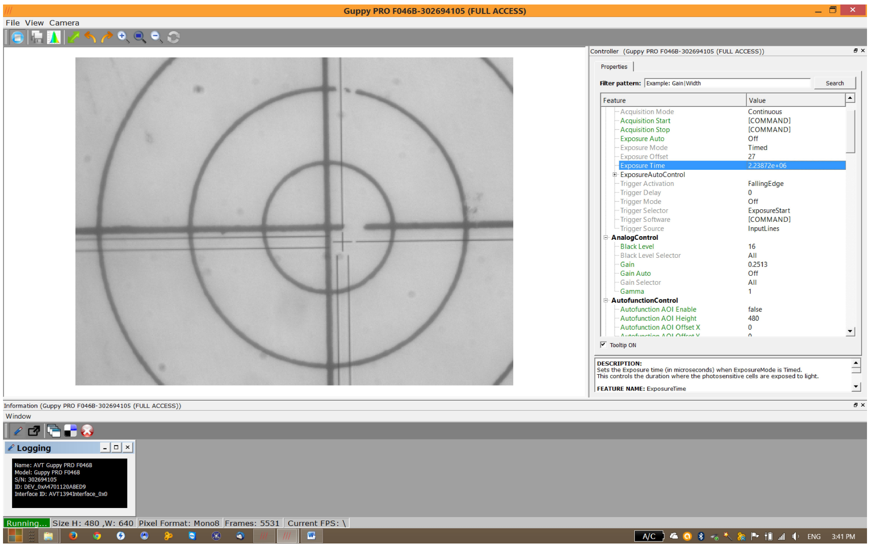

Fig. 6 – A daytime test image obtained in laboratory on a calibration target, with Guppy Pro F-046 B&W mounted on Topcon MS05AX using the AVT Vimba Viewer software.

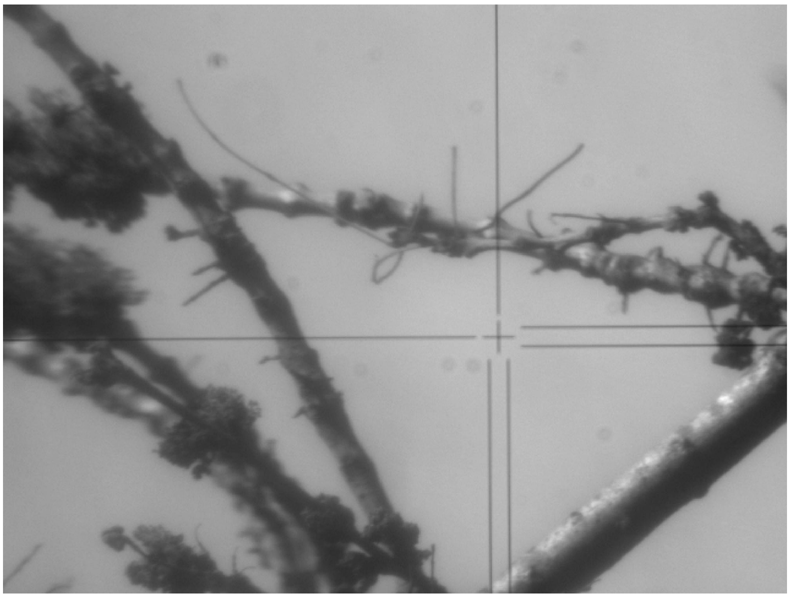

Fig. 7 – A daytime test image of a tree branch, obtained outside the laboratory with the mobile platform.

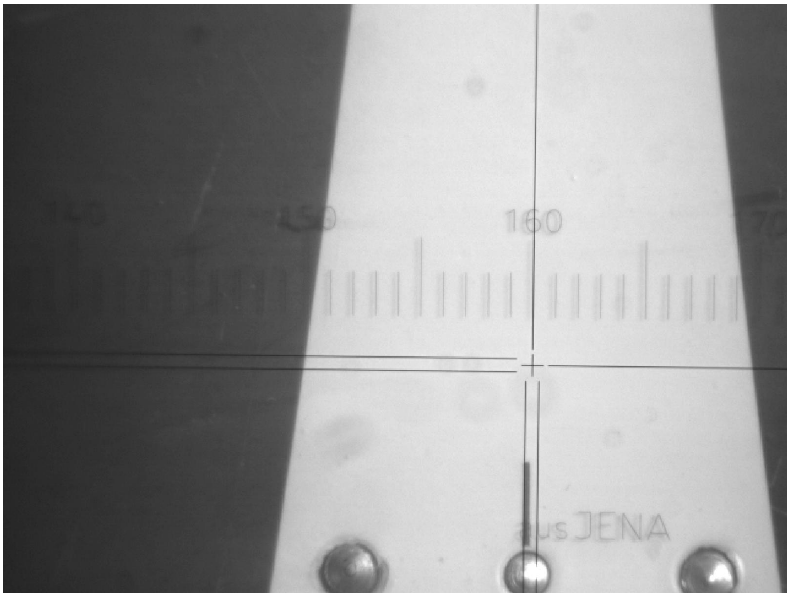

Fig. 8 – A daytime test image obtained in laboratory on a millimeter divided calibration ruler, with Guppy Pro F-046 B&W mounted on Topcon MS05AX.

REFERENCES

Hofmann-Wellenhof, B. and Moritz, H.: 2006, *Physical geodesy*, Springer Wien New York.

Rüeger, J.M. and Featherstone, W.E.: 2000, *Aust Surv* **45(2)**, 46.

Featherstone W.E.:1997, *Aust Surv* **42(1)**, 45.

Hirt, C. and Reese, B.: 2004, *Electronic Proc. IAG GGSM2004 IAG International Symposium*, Porto, Portugal

Rotaru, M., Anculete, Gh., Paraschiva, I.: 1989, *The evolution of the surveying military concept in Romania*, D.T.M., Bucureşti (in Romanian)

Bürki, B.: 2014, *Zenith camera and determination of deflections of the vertical (in Switzerland)*, `https://www.rdb.ethz.ch/projects/project\textunderscorepdf.php?proj\textunderscoreid=6106`

Hirt, C., Bürki, B., Somieski, A., Seeber, G.: 2010, *Journal Surveying Engineering*, **136(1)**, 1.

Hirt, C. and Bürki, B.: 2003, *3rd Meeting of the International Gravity and Geoid Commission*, Tziavos, I. (ed), Aug 26 2002, 161.

Popescu, P., Popescu, R., Paraschiv, P.: 1997, *Romanian Astron. J.* **7**, 189

Popescu, R. and Paraschiv, P.: 1998, *Publications of the Astronomical Observatory of Belgrade*, **60**, 110.

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