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A CONSTRUCTION OF AN ADVANCED MEASURING SYSTEM FOR ASTRO-GEODETIC DETERMINATIONS

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Abstract. The measuring system described in the paper is dedicated to fast and efficient performing of astro-geodetic determinations. It consists of: an optical instrument for precise determination of the local vertical tangent (zenitlot), professional CCD camera for acquiring a sky picture near zenith, specially constructed system for time-keeping purposes, based on a GPS controller, a laptop for maintaining the camera, and a laptop with a driver program for time registration.The main contribution of the method is the elimination of the observer error from the measuring process.

1. INTRODUCTION

European national geoids are mostly gravimetrical. The reasons are complicated procedure of astro-geodetic measurements and depreciated astrometrical instruments. Measurements last long and, therefore, are not economical. By developing advanced astrometrical instruments, determination of astro-geodetical geoids becomes more efficient. Researches on developing such advanced measuring systems are performed in Switzerland and Germany (Hirt et al. 2005) as well as in Austria (Gerstbach 1997).

Considering the requests for accuracy of astronomical coordinates used for calculation of vertical deflections, it was estimated that a modular system based on existing geodetic and astronomical equipment can be designed.

2. REVIEW OF ASTRO-GEODETIC DETERMINATIONS IN SERBIA

Most of astro-geodetic observations in Serbia are performed in the first half of 20^{th} century, between 1900 and 1911 (Bošković 1952). A person who led most of those measurements was Stevan Bošković, a general of Serbian army. He measured 30 latitudes and 30 azimuths, using Pevtsov and Tsinger methods for latitude determinations. Azimuths were measured indirectly, by observing Polaris in an arbitrary hour angle. Instrumentation for two measuring crews consisted of two Kern universal instruments, 12 chronometers, aneroids and thermometers.

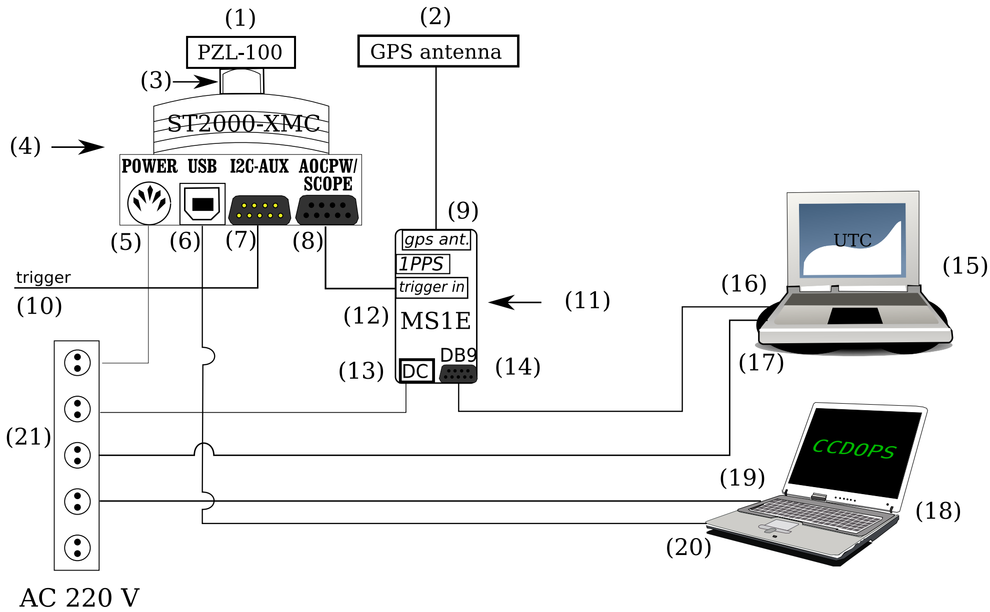

Figure 1: The scheme of the modular system.

Between two world wars there were three broad measuring campaigns:

- Meridian arc measurements,
- Measurements of the mean parallel 45, and
- Determinations of Belgrade longitude.

After World War II, astro-geodetic measurements were performed by:

- Military Geographic Institute (MGI),
- Federal Geodetic Directorate (FGD),
- Astronomical Observatory, and
- Institute of Geodesy.

Today, the main role of geodetic astronomy is refining the geoid solutions. Researches on new instruments design are held within the Faculty of Civil Engineering, Chair for Geodesy and Geoinformatics, and one of the measuring systems is presented in the paper.

3. INSTRUMENTATION AND MEASURING METHODS

3. 1. A DESIGN OF THE MODULAR SYSTEM

The instrument was designed as a modular system. The main reason for such solution is its complexity and the fact that the components incorporated in the system are used daily for other purposes. The scheme of the measuring system is given in the Fig. 1, with components are numerated from (1) to (21).

An optical instrument used for observing zenith stars was zenitlot Zeiss PZL-100 (1). It is an instrument typically used in applied geodesy, for verifying the directions of high vertical object. The construction of zenitlot is similar to a precise level Zeiss

Koni NI007, with an objective glass mounted vertically, instead parallel to an eyepiece. Both instruments have a special calibration system for vertical compensation, so a local vertical tangent can be achieved in 10-20 seconds, with 2" accuracy. The optics of zenitlot allows one to see geodetic stars, i.e. up to 6^{th} magnitude.

A CCD camera SBIG ST2000-XMC (4) was used for acquiring snapshots of a star field near zenith. The camera is mounted to zenitlot's eyepiece by a custom adapter (3), so it stands alongside of zenitlot. It is powered via Power port (5). All components of measuring system were powered by 220 V source (21).

A design of the GPS micro-controller was customized for time-keeping during a measuring session. That is why a GPS micro-controller with 1 Pulse Per Second (1PPS) capability was needed. A GPS chip is placed in a box (11). The box is supplied with three BNC connectors: GPS antenna input (9) for connection with GPS antenna (2), 1PPS for internal clock calibration, and trigger-in (12) for inducing the driver programme. There is one input RS232 port, and two I/O RS232 ports (14). All ports are DB9 types. The 6V power was established by an AC/DC adapter (13). Input port is used in equal heights measuring method when a digital theodolite is connected to it. Other two ports connect GPS micro-controller with a laptop computer. Since GPS messages are transmitted and received via RX and TX pins of DB9, other pins had to be used for 1PPS and trigger purposes.

Registrations of time tags were cached by an interrupt routine written in low C and assembler. The time scale for measuring time tags was defined by a number of ticks of the computer's clock counted from a moment of turning on the computer. The unit of the scale is a cycle. The resolution of a cycle depends on the computer clock's frequency. For example, the computer used in the experiment was a Pentium I with 133 MHz clock, so the resolution of a cycle was about $1 \cdot 10^{-8}$. PPS ticks are cached via serial port (16).

Two laptops were used. SBIG application for maintaining CCD cameras CCDOPS was installed on a laptop (18) that served as a data server. Acquired images were logged automatically, via USB port (20) connecter with USB port (6) on the CCD camera. Filenames of log files were created by the software, after defining the common prefix of the log files. Second laptop, dedicated to time-keeping purposes, ran under DOS. Windows OS was avoided because of its latencies and unpredictable states of a running process. The driver programme was written in C++ and compiled with Borland C++ compiler suite. The most critical part of the driver, the 1PPS and trigger handling routine, was written as an interrupt function. Several instructions dealing with listening to RS232 interrupts and reading clock's state (via specific processor's registers) were programmed in assembler.

Acquiring of an image was started after ignition of trigger (10) connected to I2C-AUX port of camera (7), which was performed manually. It did not have any further influence to the accuracy of measurements, since the moment of ignition was recorded with the same resolution as PPS ticks.

3. 2. MEASURING METHOD

Interpolation of local zenith was performed by taking a snapshot of a star field near zenith. A fictious star in the zenith is in the same time in its culmination, so its declination circle fits to the meridian, which means its declination equals to the latitude of the station.

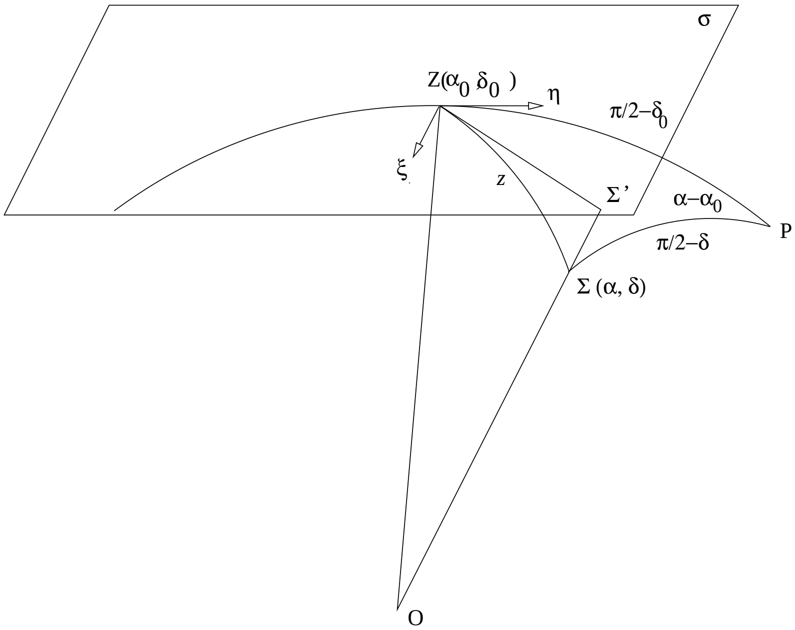

Figure 2: Tangential coordinates.

Since the hour angle of the star in the culmination equals zero, Local Apparent Sideral Time (LAST) is:

$$LAST = \alpha. \tag{1}$$

If the Greenwich Apparent Sideral time (GAST) is:

$$GAST = LAST - \Lambda, \tag{2}$$

the connection between astronomical coordinates of the station $((\Phi, \Lambda))$ and equatorial coordinates of the zenith star $((\alpha_z, \delta_z))$ is:

$$\begin{aligned} \Phi &= \delta_z \\ \Lambda &= \alpha_z - GAST, \end{aligned} \tag{3}$$

However, stars usually do not pass the zenith, so the place of the zenith is interpolated by measuring the places of stars near zenith. Tangential coordinates, defined by a tangent plate in the zenith point, are used for transforming central to orthogonal projection of a zenith field image (Fig. 2). The relation between tangential (ξ, η) and equatorial coordinates is as follows:

$$\begin{aligned} \xi &= \frac{\cos\delta \sin(\alpha-\alpha_0)}{\sin\delta \sin\delta_0 \cos\delta \cos\delta_0 \cos(\alpha-\alpha_0)} \\ \eta &= \frac{\sin\delta \cos\delta_0 - \cos\delta \sin\delta_0 \cos(\alpha-\alpha_0)}{\sin\delta \sin\delta_0 + \cos\delta \cos\delta_0 \cos(\alpha-\alpha_0)}. \end{aligned} \tag{4}$$

which can be transformed by elementary transformations to (Seeber 1993):

$$\begin{aligned} \xi &= \tfrac{\tan(\alpha-\alpha_0)\cos q}{\cos(q-\delta_0)} \\ \eta &= \tan\left(q-\delta_0\right), \end{aligned} \tag{5}$$

with:

$$\cot q = \cot\delta\cos\left(\alpha-\alpha_0\right). \tag{6}$$

Transformation between image and tangential coordinates is given by the projective transformation:

$$\xi = \frac{Ax+By+C}{Kx+Ly+1} \tag{7}$$

$$\eta = \frac{Dx+Ey+F}{Kx+Ly+1} \tag{8}$$

To estimate the transformation parameters A, B, C, D, E, F, K i L, at least four common stars are needed, i.e. stars with both image and tangential coordinates known. If there are more than four common stars, transformation parameters are calculated using a least squares adjustment.

The place of the zenith is interpolated through an iterative process. First the approximate equatorial coordinates of a zenith star should be adopted:

$$\begin{aligned} \alpha_0 &= LAST \\ \delta_0 &= \phi \end{aligned} \tag{9}$$

Inverted formulae (4) are used for calculating the interpolated direction of projection center, i.e. local vertical:

$$\alpha_z = \alpha_0 + \arctan\frac{\xi_Z}{\cos\delta_0-\eta_Z\sin\delta_0} \tag{10}$$

$$\delta_z = \arctan\frac{(\eta_Z+\tan\delta_0)\cos\left(\alpha-\alpha_0\right)}{1-\eta_Z\tan\delta_0}. \tag{11}$$

In the next iterations, approximate coordinates (α_0, δ_0) get the values from previous iteration (α_z, δ_z). After few iterations the difference between two pairs of coordinates (α_z, δ_z) goes below miliarcsecond (Hirt 2001).

The astronomical coordinates are calculated according to (3).

4. RESULTS

Some of the results obtained by the described measuring system are given in Table 1.

First four rows of Table 1 are self-explained. The values of $\Delta\Phi$ and $\Delta\Lambda$ shows the convergence of the iterative process. Five iterations were needed to get the acceptable results. According to Hirt (2001), even less iterations (two or three) should suffice the accuracy requests, when more advanced instruments with better optics are used. But, even with this portable system, root mean square agrees with assumed mathematical model, displayed as σ_0 values.

Table 1: Results

Iteration	1	2	3	4	5
ξ_0	-0,39193	-0,09498	-0,00094	0,00481	0,00054
η_0	0,30169	-0,07087	-0,00532	0,00315	0,00062
Φ	0,7874369	0,7874318	0,7874314	0,7874316	0,7874317
Λ	0,3716323	0,3716225	0,3716224	0,3716229	0,3716230
$\Delta\Phi$["]	4,525	-1,063	-0,080	0,047	0,009
$\Delta\Lambda$["]	-8,331	-2,019	-0,020	0,102	0,011
A	-0,41076	-0,27311	-0,27300	-0,27300	-0,27300
B	0,08253	0,05657	0,05616	0,05609	0,05612
C	119,31582	78,13306	78,45706	78,56605	78,56783
D	0,06542	0,04319	0,04308	0,04310	0,04311
E	0,39273	0,26261	0,26190	0,26195	0,26198
F	-77,33344	-52,03102	-52,27364	-52,21987	-52,21525
K	-0,00004	0,00001	0,00000	0,00000	-0,00001
L	0,00062	0,00011	0,00038	0,00039	0,00039
σ_0	1,10100	0,90136	0,98135	0,95443	0,95383

5. CONCLUSION

The modular system for astro-geodetic observations can speed up determinations of astro-geodetical vertical deflections. The portability of the instrument is an advantage, because any geodetic point can be reached. The automation raises the reliability of measurements. The main contribution is the fact that the observer error was eliminated from the measuring process, because time-keeping is derived as an automatic process, implemented as an interrupt function in the driver programme.

It is expected that new measuring campaigns will be organized, so instrumental solutions presented in the paper can be applied.

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