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CCD TECHNIQUE FOR LONGITUDE/LATITUDE ASTRONOMY

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Abstract. We report about CCD (Charge Coupled Device) experiments with the instruments of astrometry and geodesy for the longitude and latitude determinations. At the Techn. University Vienna (TU Vienna), a mobile zenith camera "G1" was developed, based on CCD MX916 (Starlight Xpress) and F=20 cm photo optic. With Hipparcos/Tycho Catalogue the first results show accuracy up to $0.''5$ for latitude /longitude. The PC - guided observations can be completed within 10 minutes. The camera G1 (near 4 kg) is used for astrogeodesy (geoid, Earth's crust, etc.). At the Belgrade Astronomical Observatory (AOB), the accuracy of (mean value of) latitude/ longitude determinations can be a few $0.''01$ using zenith stars, Tycho - 2 Catalogue and a ST-8 of SBIG (Santa Barbara Instrument Group) with zenith-telescope BLZ (D=11 cm, F=128.7 cm). The same equipment with PIP instrument (D=20 cm and F=457.7 cm, Punta Indio PZT, near La Plata) yields a little better accuracy than the BLZ's one. Both instruments, BLZ and PIP, were in the list of Bureau International de l'Heure - BIH. The mentioned instruments have acquired good possibilities for semi or full-automatic observations.

1. INTRODUCTION

Because of better possibilities (accuracy, etc.) of new technic (Lunar Laser Ranging - LLR, Satellite Laser Ranging - SLR, Very Long Baseline Interferometry - VLBI, Global Positioning System - GPS, etc.), after 1988 and the transformation of Bureau International de l'Heure - BIH into International Earth Rotation Service - IERS and Bureau International des Poids et Mesures - BIPM, the observations of latitude and universal time variations by using the classical astronomical instruments declined.

During the last few years, the CCD technic with computer manipulation and calculation open new exerts and big influence on classical astrometry and geodetic instruments. It means that there are some new possibilities for classical astrometry.

At the AOB there is a zenith-telescope BLZ and at Punta Indio there is a photographic zenith tube (PZT) PIP. Also, at the AOB there are several very good CCD cameras. In this paper we paid attention to the SBIG ST-6 and ST-8. The ST-6 are with 375×242 pixels (1530×1020 for ST-8), 23×27 mikrons pixel size (9×9 for ST-8) and 8.6×6.5 mm array dimension (13.8×9.2 for ST-8). We made the investigations of the accuracy of longitude/latitude determinations by using CCD technic with BLZ and PIP instruments. The experience of AOB and TU Vienna, with CCD technic, was taken under our consideration.

By virtue of the same reasons, the astro-geodesy has got interesting new practicability with the CCDs (good accuracy of geoid determination via astro-geodesy longitude and latitude observations, etc.). At the TU Vienna there is the CCD MX916 with 752×580 pixels count, 11×12 mikrons pixel size and 8.7×6.5 mm active area. The G1 with CCD is under development at the TU Vienna for astro-geodesy objectives.

2. BLZ AND PIP INSTRUMENTS WITH CCD

The instruments presented here, were in the list of BIH: the Belgrade zenith-telescope denoted BLZ (D=11cm, F=128.7cm) and the Punta Indio photographic zenith tube denoted PIP (D=20cm, F=457.7cm).

They participated with their observations (BLZ interval was 1949.0-1986.0 and PIP one 1971.6-1984.5) and took a part in "Earth orientation parameters 1899.7-1992.0 in the ICRS based on the HIPPARCOS reference frame" (Vondrak et al. 1998) with very good weights (among 48 instruments of different types): for BLZ the weight of one observation in latitude was 0.93, and for PIP it was 2.07 and in time 1.96 .

Before the real observations, it is necessary to find a good focus (for each CCD plus optic) and optimal exposure time which depends on observed objects and scientific objectives (Martinez and Klotz 1998).

From the catalogue, we need to take astrometrically "good" stars (to find the min. and max. values of star's magnitude for our CCD and optics, to remove double stars which are not good for precise measurements, to remove the stars with bad position accuracy or without proper motion data, etc.). Nowadays, the Tycho-2 Catalogue (Hog et al. 2000), at ICRS reference system, is very useful for astrometrical observations. The positions are precise to near 60 mas (for all stars), the proper motions are precise to about 2.5 mas/yr, and about 100 000 stars (only 4%) are without proper motion data. The star density is about 150 stars/sq.deg. for $b = 0^o$ (50 stars/sq.deg. for $b = \pm 30^o$, and 25 stars/sq.deg. for $b = \pm 90^o$) and V is near 11.5 mag (with 90% completeness).

During the observations, the computer - CCD connection is of great importance. Also, each astronomical or other instrument needs a good adapter (the connection for mounting CCD on the telescope), and can be the instrument's shutter for better exposure time determination (CCD plus computer exposure time can be with some systematic error). Also, the computer time can be replaced with input time (more precise) for precise time measurement (if it is necessary for reduction).

If we use the CCD with the BLZ's tube in the zenith direction and PZT procedure of observation (four exposures of the same zenith-stars with 180 deg. turns of BLZ, between exposures, around its vertical axis) it is possible to determine both coordinates of observed place (longitude and latitude). For PIP with CCD, the process of measurement is like that with the PZT (as it was with photo plate in the past), and it is necessary just to discard the observations by photo plate and to adopt CCD. Both instruments (BLZ and PIP) can be semi-automated or full-automated.

The sky field of BLZ with CCD ST-8 (1."44/px for both, x and y, axis) can be about 37'×25' (about 10'×7' for PIP) and by using Tycho-2 Catalogue we can catch about 20 stars (a few stars for PIP) which is enough to reach the longitude/latitude accuracy of about a few 0."01 (PIP can achieve nearly double accuracy than BLZ because of better optic). We made experiments during 2001 at IGG TU Vienna by using G1 and CCD MX916 (see below, the two CCD figures - observations that can reach the latitude accuracy of 0."89) and if we compare F of BLZ with one of G1 (128.7cm/20cm) or F of PIP with that of G1 (457.7cm/20cm) the longitude/latitude accuracy can be better by using BLZ or PIP with CCD ST-8; also, the ST-8 achieves higher quality for astrometry than the MX916 (the ST-8 has got 1530×1020 pixels, but the MX916 has got 752×580 ones). Another important note: the BLZ levels (for instrument orientation into the zenith direction) are nearly 1" per division (pars), but the G1 ones are more than ten times worse. The standard error of unit weight (for BLZ and PIP longitude/latitude determination) was about 0."15 by using visual (for BLZ) and photo plate (for PIP) observations (Vondrak et al. 1998); the error of the mean value was several times better because of the observations of more stars (group of stars) during about one hour. In the case of BLZ, the error of the mean value reached 0."05. This means, our predicted accuracy of the mean value (of longitude/latitude), for BLZ and PIP with one CCD image procedure (with about 20 Tycho-2 stars for BLZ field and a few stars for PIP) is better than with the visual or photo plate. And the CCD observations can be completed in just a few minutes (see below, the two CCD figures - observations).

3. TRANSPORTABLE GEODETIC ZENITH CAMERA

In geodesy, the rapid determination of the direction of the vertical has 3 additional goals, too:

a) geoid determination by use of Vertical Deflections (VD) along profiles, where VD is the difference between real (astrometric) vertical and ellipsoidal vertical of a point,

b) accurate reduction of terrestrial networks to the reference ellipsoid,

c) inversion of VDs to determine density structures of the Earth's crust.

Geoid projects in flat countries mainly use gravimetry. Observation time is very short, but to get high geoid accuracy 200 - 500 points per 1000 km^2 are necessary, whereas astrogeodesy requires only 10 - 20 VD points (Gerstbach 1997). Therefore in alpine countries an astrogeoid is much more effective than gravimetry.

At the TU Vienna a special research project "CCD IN ASTRO-GEODESY" started in 1999, sponsored by Oesterreichische Nationalbank. The main goal is to develop automatic measurement methods, and if possible to speed them up. During the first 2 years CCD cameras of the photo market (Olympus 800) were used, mounted at the eye-piece of a Zeiss astrolabe (4/20 cm) and a Kern theodolite DKM3a (7/40 cm). The accuracy was ±1" as expected (Gerstbach 2000), but the measuring time not shorter than visual. Therefore we changed the project toward the development of a small zenith camera.

Currently we test an astro CCD camera Starlight MX 916. It has 752×580 pixels (with 11×12 mikrons and the sensor 8.7 × 6.5 mm) which can be binned (electronic mix of 2×2 pixels) to increase the sensitivity. A prototype of zenith camera is under construction with a photo tele objective 1:4 / 20 cm. In the vicinity of Vienna exposures of $5^s - 10^s$ show stars up to 12^{th} magnitude.

Four CCD images with the G1 in the meridian direction were taken within a few minutes. The expositions are controlled by a notebook computer. The relation between rotating axis and vertical is measured by two spirit levels mounted on the camera turning plate. The usable field of view is about $1^o30^{'} \times 2^o$. According to first tests the images show 20 - 50 stars, but the faintest stars are not used for measurements. The internal accuracy is about ±1" with 10 Hipparcos (ESA 1997) stars and almost ±0."5 with 20 Tycho stars (see CCD figures below), but the systematic error can be bigger than 1" because of bad levels. Combining four images and with better quality levels we expect real accuracies of ±0."5 (for example, if we replace the present levels with better ones our accuracy is going to be better).

The presented CCD observations (Fig. 1. and Fig. 2.) are made for the illustration. They are made at IGG TU Vienna with G1 and CCD MX916. The date was October 31st, 2001, the temperature was about 16^oC, the air pressure was near 990 mb, $UTC = 17^h36^m1^s.28$ for the Fig. 1. ($UTC = 17^h36^m51^s.45$ for the Fig. 2.), the exposure times were 10^s (because of this, the visible stars appear not like a points but as short lines and the middle of each line is in accordance with the middle of exposure time), the time period between the exposures was about 50^s, the G1 was turned 180^o around the vertical axis after each exposure. At IGG TU Vienna, there is a programme for reduction of CCD observations which we used for our investigations. The programme offers necessary options (open for the users) and can process the CCD figures automaticly. After the reduction of presented CCD observations (the Fig. 1. and Fig. 2.), the latitude accuracy was 0."89. During our astro-geodetic CCD observations and investigations at IGG TU Vienna, there were the CCD observations which gave us the results with better and worse accuracy than presented one, but up to 0."5 . The movements of the stars visible in Fig. 1. are up and in Fig. 2. are down (in line with the parallels on the sky), and because of the turning G1 around the vertical axis by 180^o between the exposures (the pause between the observations is 50^s) it is possible to see in Fig. 2. very big number of the stars presented in Fig. 1., but just on the other side of the Figure. If some star is visible in Fig. 1. on left side of the figure and down, we can see it in Fig. 2. on the right side and up. For latitude measurements, we used the stars presented on both CCD figures, but at the first figures before the local meridian and at the second one after it. For both coordinates, longitude and latitude measurements, we need four CCD figures, two before and two after the meridian, as it is for the PZT instrument.

4. CONCLUSION

Following the experiences of AOB (with CCD SBIG ST-6/ST-8), and the observations/results and investigations made at IGG TU Vienna (the project "CCD in der Geodatischen Astronomie") by using the G1 with CCD MX916 and the Hipparcos/Tycho Catalogues we can conclude: the level of accuracy of the mean value of

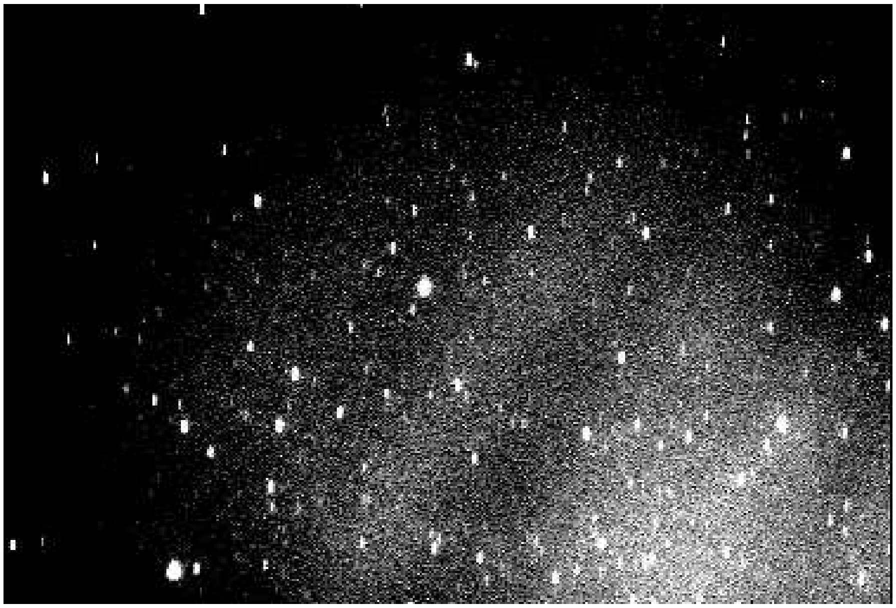

Figure 1: The observations of G1 with CCD MX916.

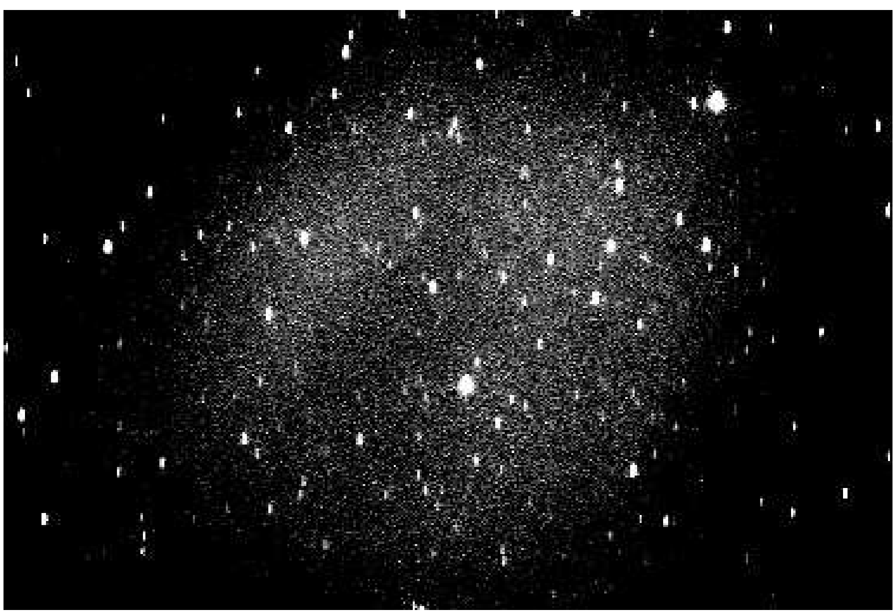

Figure 2: The observations of G1 with CCD MX916.

longitude/latitude determination by using CCD ST-8 with BLZ/PIP and Tycho-2 can be a few $0.''01$ (PIP is with better optic and it can yield us nearly double better accuracy than BLZ one), for G1 (with CCD MX916, Tycho-2 and better levels) the accuracy for astro-geodesy is going to reach $0.''5$, the ST-8 has got better resolution than MX916 and can yield us better accuracy, it is possible to adapt BLZ/PIP for CCD technic (also, to adapt BLZ to operate as PZT) and to make semi-automatic or full-automatic observations. Also, BLZ and PIP with CCD can be useful for another kind of observations (to determine the coordinates of the stars, their proper motions, etc.).

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