# SOME RESULTS OF CCD-CAMERA BASED ASTROMETRIC PLATE MEASUREMENTS

N. ZACHARIAS[1], C. de VEGT[2], L. WINTER[2] and W. WENEIT[2]
[1] *U.S. Naval Observatory, 3450 Mass. Av. NW., Washington D.C. 20392-5400, U.S.A.*
[2] *Hamburger Sternwarte, Gojenbergsweg 112, W-2050 Hamburg 80, Germany*

ABSTRACT. A measuring accuracy of about 0.3 μm per coordinate for well exposed stellar images is achieved over the entire usable measuring area of more than 200 x 200 $mm^2$ with the CCD-camera upgrade of the 'old' Mann comparator.

The external plate-to-plate comparison shows that the error due to emulsion shifts dominates, which results in an overall accuracy of about 0.8 μm.

## 1. The HAM I System

The Hamburg Observatory Mann 422F comparator has been upgraded with a Hamamatsu $(256 \text{ pix})^2$ CCD camera and is fully controlled by a MicroVAX II computer. This system, the first Hamburg Astrometric Measuring Machine (HAM I), has been in routine operation since 1991.

## 2. Calibration of the x, y Table

Each axis was calibrated separately with the help of a calibrated glass scale, and a straightness calibration was achieved using a wire in two orientations. Then a high precision grid-plate ($\sigma = 0.2$ μm) was measured in two orientations. The standard deviation of (HAM I – grid) is $\sigma_x = 0.24$ μm and $\sigma_y = 0.27$ μm, thus only a noise of about $\sigma = 0.17$ μ is introduced by the HAM I measurement (residual calibration errors).

## 3. Repeatability

For testing the stability of the camera and the illumination system, a fiducial mark was measured without moving the carriage. After the usual warming-up period of 2 hours, a standard deviation of $\sigma = 0.05$ μm for the **static** repeatability is reached.

A list of 10 uniformly distributed fiducial marks on the grid plate were measured in one orientation 100 times in a single 16-hour run. A standard deviation of $\sigma = 0.25$ μm for this **dynamic** repeatability was obtained.



*H. T. MacGillivray et al. (eds.), Astronomy from Wide-Field Imaging,* 285–287.

## 4. Position Comparison of Radio Stars

To provide an external accuracy estimation, plates of six radio stars (Black Birch Astrograph, 100″/mm) were used. Taking all individual positions of individual exposures of one star, the standard deviation (of one image) can be calculated (Table 1). Note that the numbers quoted in Table 1 include also error contributions from the plate adjustment process to the reference stars, emulsion shifts and effects due to the Earth atmosphere.

**Table 1.** Plate to plate accuracy of an object at the centre of the plate. The numbers given are standard deviations for a single observation (image). The plate scale is 100″/mm (100 mas = 1μm).

| Star | $n_{Plates}$ | $n_{exp}$ | order | $\sigma_{\alpha\cos\delta}$ | $\sigma_\delta$ | |
|---|---|---|---|---|---|---|
| S Crt | 5 | 10 | 0 | 40 mas | 29 mas | |
| HD 50896 | 4 | 7 | 0 | 119 mas | 110 mas | |
| | | 8 | 1 | 89 mas | 30 mas | |
| HD 50896 | 4 | 8 | 0 | 87 mas | 52 mas | *) |
| FR Sct | 4 | 8 | 0 | 88 mas | 134 mas | |
| KQ Pup | 4 | 8 | 0 | 111 mas | 85 mas | |
| | | 8 | 1 | 78 mas | 107 mas | |
| RV Lib | 4 | 8 | 0 | 48 mas | 59 mas | |
| TY Pyx | 4 | 8 | 0 | 33 mas | 67 mas | |
| quadratic mean: | | | | 82 mas | 82 mas | |

$n_{Plates}$ = number of plates for object
$n_{exp}$ = number of exposures used for statistics (there are 1 or 2 exposures on a plate)
order = diffraction grating order, 0 = central image, 1 = first order diffraction images
*) a second epoch observation of HD 50896

## 5. Measuring Accuracy over the Entire Plate Area

A total of 2700 GSC stars down to 13.5 mag have been measured in a plate area of about 6 x 6 deg$^2$ on four plates of the field 0912+298 taken during one night (Hamburg Zone Astrograph, 100″/mm).

Each plate was measured in 2 orientations. The measurements of the first orientation were transformed onto the second using an orthogonal model after applying the calibration model to the raw x, y data. A subset of stars (6th to 9th mag) distributed over the entire plate area was used. A standard error for the transformation of $\sigma_T$ = 0.49 μm is obtained, thus the error of a single measurement is about 0.35 μm. This includes fit errors of the measured star profiles as well as residual calibration errors.

## 6. Plate to Plate Accuracy over the Entire Plate Area

For each of the 4 plates of the above example, mean x, y coordinates of measurements in 2 orientations have been calculated. Then a plate-to-plate comparison was performed using a suitable transformation model (Table 2), and the position differences in x, y for all stars (quadratic mean) were calculated. Thus the error of one star position on one plate is about 0.75 µm. This error includes besides all measuring machine dependent errors, the contribution of the emulsion shift. The significant difference between $\sigma_T$ and $\sigma_x$, $\sigma_y$ can be accounted for by a magnitude equation between plates. Thus a clear separation of measuring machine dependent errors and other errors is demonstrated here, proving the high measuring precision of HAM I.

**Table 2.** Transformation of x, y coordinates on a plate to plate basis

| Plates | Model | $n_T$ | $\sigma_T$ /[µm] | $n_{stars}$ | $\sigma_x$ /[µm] | $\sigma_y$ /[µm] |
|---|---|---|---|---|---|---|
| 641 - 642 | mod 2 | 2625 | 1.18 (x) | | | |
| | | 2625 | 1.13 (y) | | | |
| 641 - 642 | mod 3 | 126 | 1.00 | 2636 | 1.32 | 1.31 |
| 641 - 643 | mod 3 | 118 | 1.16 | 2614 | 1.53 | 1.78 |
| 641 - 644 | mod 3 | 122 | 1.06 | 2650 | 1.47 | 1.35 |
| 642 - 643 | mod 3 | 118 | 0.93 | 2584 | 1.49 | 1.82 |
| 642 - 644 | mod 3 | 122 | 1.02 | 2619 | 1.37 | 1.29 |
| 643 - 644 | mod 3 | 116 | 0.94 | 2621 | 1.41 | 1.64 |

model: mod 2 = affine transformation, separate for each coordinate
mod 3 = affine + tilt terms, x, y coupled

$n_T$ = number of transformation stars used
$\sigma_T$ = standard error of transformation
$n_{stars}$ = number of stars for difference statistics
$\sigma_x$ = quadratic mean differences in x
$\sigma_y$ = quadratic mean differences in y

https://doi.org/10.1017/S0074180900047483 Published online by Cambridge University Press