THE GUIDE STAR CATALOG. II.
ASTROMETRIC AND PHOTOMETRIC ALGORITHMS AND PRECISION.

JANE L. RUSSELL[1,2], BARRY M. LASKER[2], AND HELMUT JENKNER[2,3]

[1] *E. O. Hulburt Center for Space Research, U.S. Naval Research Laboratory and*
Applied Research Corporation

[2] *Space Telescope Science Institute*[4]
Baltimore, Maryland, USA

Abstract: The algorithms used in photometric and astrometric calibration of the Guide Star Catalog, as well as the analyses of the related errors are discussed. The precision requirements of $0\farcs33$ for relative positions and of $0\fm4$ for photometry are generally fulfilled.

I. INTRODUCTION

The photometric and astrometric data in the Hubble Space Telescope (HST) Guide Star Catalog (GSC) are based on the image processing described in the first paper of this series, specifically on a photometric parameter which estimates the integrated photographic intensity above a threshold as produced by the COSMOS algorithm (Lutz 1979)[5] or a related construct for blended images, and on astrometric x, y measurements produced by a seven parameter, modified Gaussian centroider.

II. PHOTOMETRIC DATA REDUCTION

The reference data for the photometric data reduction are a sequence of six stars, roughly in the range from $9\fm0$ to $14\fm5$, which were generally chosen to be near the center of each plate, near at least 2 SAOC stars, and within a one-half degree square. Each star in the sequence has photoelectric B and V magnitudes with a precision of $0\fm05$. At the time of this Symposium, the Guide Star Photometric Catalog (GSPC, Lasker *et al.* 1987), including detailed finding charts, is in the final stages of preparation for publication.

The least-squares solution fits the logarithms of the photometric parameters to the reference magnitudes, generally with a second-order fit, but for a small percentage of the plates a curve of first or third order was used. The photometric sequence generally had a formal error of $0\fm05$. As an independent check, the GSC magnitudes were compared to those from the $\delta = +28°$ band of sky observed by McGraw et al. (1987) using the CCD Transit Instrument of the University of Arizona. Tentatively, the results show differences of the order of $0\fm25$ *rms* between the two surveys. A worst case estimate of the precision of the magnitudes comes from the comparison of calculated magnitudes of stars which appear on

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[5] References for all three papers of this series can be found at the end of Paper III.

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more than one plate. The plate to plate differences may be as high as $1^{m}_{\cdot}0$ but are generally about $0^{m}_{\cdot}5$.

III. ASTROMETRIC DATA REDUCTION

The reference catalogs for the astrometric data reduction are the AGK3 in the north and the SAOC in the south. This coincides with the dividing line between the two plate surveys so that the Palomar plates are reduced with the AGK3 and most of the SRC plates are reduced using the SAOC for reference. The exception to the latter is for plates centered at $\delta = -65°$ to $-90°$, where we used the CPC. This is because at the time of the construction of the SAOC, the CPC, on which most of the southern SAOC was based, was only completed to $\delta = -64°$ (Eichhorn, 1974). No catalog corrections were introduced, since each GSC plate solution used only data from one catalog and the plate solutions are catalogued independently.

The x, y measurements were determined from the scan data according to the algorithm described in the first paper of this series. Because of the problems with centroiding images of the very bright stars, we did not use any reference stars brighter than $7^{m}_{\cdot}5$ in the astrometric solutions. This had the added benefit of eliminating most of the Boss General Catalogue (GC) stars from the SAOC. According to Eichhorn (1974), the GC stars have a systematic error within the catalog.

The plate model was based on extensive testing, not only for the most accurate astrometric solution, but also for the most successful pointing of the Space Telescope (Russell and Williams, 1986). Because of the pointing algorithm used by the HST, the relative positions, *i.e.* separations, of two guide stars and the observing target are the only astrometric information critical to the spacecraft's operation. The separations are required to have a precision of $0''\!.33$, or a single position to have a precision of $0''\!.25$. This meets the specification that targets can be placed in a $2''$ square aperture with 99% reliability. The astrometric testing included not only investigations into the astrometric precision, but simulated pointings in test fields to verify that the specifications were met.

The plate model includes ten constants in each of the ξ and η coordinates; it appears as a general third order polynomial, and only includes geometric terms, *i.e.*, no terms using magnitude or color are used. Some magnitude-related effects were noted, especially at the plate edges, but attempts to remove them resulted in less effective pointing of the telescope. The plate model is of the most general form used for Schmidt telescopes. Further testing showed that pre-corrections or other attempts to use less than the most general form of the plate model adversely affect the internal precision of the solutions. Details will be included as part of the forthcoming Guide Star Catalog publications.

The standard errors of unit weight of the plate solutions vary with the precision of the reference catalog from about $0''\!.4$ in the north to $1''\!.5$ in some areas of the south. The GSC includes a single entry for the precision of the positions; it is the square-root of the sum of the squares of the ξ and η errors, calculated rigorously from the full covariance matrix of the solution. This calculated error estimate may be several seconds of arc for stars in the extreme plate corners from the least accurate areas of the SAOC. Admittedly this is not realistic, but was allowed because it discouraged choosing guide stars from plate corners for HST operations.

Another way of checking the astrometric precision is to look at the plate-to-plate differences for positions of stars which appeared on more than one plate. As for the photometry above, this provides a worst case estimate. For the check-plates examined to date, the largest plate-to-plate differences are about $3''$; none are as large as $4''$; however, the typical values for the positional differences computed for common stars from adjacent plates are generally about 0″.5. These are approximately the values expected from the plate solutions and the internal precision of the measurements. However, even in the plate corners the relative positions have a precision of 0″.25 and so will successfully point the telescope; and when guide stars and targets require data from different plates, a local astrometric overlap solution is performed to remove the systematic differences.

Advanced astrometric algorithms, which are based on the plate to plate differences and are currently being investigated, may lead to removal of the largest errors from the plate edges within the GSC.

IV. MAINTENANCE AND ENHANCEMENTS

Two items have the highest priority for improvements to the GSC astrometry and photometry:

- New image processing with enhanced algorithms will improve both the photometry and the astrometry.
- Melding the 1500 individual plate solutions into one catalog will provide the best catalog for the user.

The first step to maintaining and improving the GSC, as suggested in the first paper of this series, is to adopt a new catalog structure for later versions of the GSC, which separately stores the observed data, *i.e.* x, y, and image parameters, as well as the algorithmic constructs, *i.e.* plate solutions and photometric calibrations, and applies the latter to the former only in staging the catalog for the consumer. Then, changes in either the image processing or the data reductions can be adopted easily, only by changing the pointers in the catalog staging software.

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