THE GUIDE STAR SELECTION SYSTEM AND THE GUIDE STAR CATALOG FOR SPACE TELESCOPE

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ABSTRACT. The Guide Star Selection System (GSSS) will provide relative positions of two guide stars and the target for each observation of the Space Telescope as well as photometry for the guide stars. Being developed at the Space Telescope Science Institute, the GSSS is a production system which is based on PDS measurements of Schmidt survey plates. The specified accuracy for the system is +/- 0.33 arcsec for the separation of the guide stars and 0.4 mag in the bandpass of the Space Telescope's Fine Guidance Sensors. The GSSS will produce two catalogs which will be used in the operation of the system. The Guide Star Photometry catalog includes photoelectric measurements (+/- 0.05 mag) in B and V for six stars over the guide star range, 9.0 to 14.5 visual magnitude, near the central part of each 6 by 6 deg survey plate. The Guide Star Catalog will include the list of all possible guide stars and brighter, positions (at least +/- 1 arcsec) and magnitudes (at least +/- 0.4 mag) for essentially the whole sky complete to visual magnitude 15.

1. GUIDE STAR SELECTION SYSTEM (GSSS) RESOURCES

The GSSS is a system which can identify possible guide stars within the visual magnitude range of 9.0 to 14.5 for a chosen target, and provide positions of the stars and the target within 0.33 arcsec and photometry of the guide stars within 0.4 visual magnitude. Though neither of these accuracies are considered as "high precision" within their respective disciplines, the sheer size of the project, that these must be provided on demand for a region of the Space Telescope field of view, 28 arcmin in diameter, in any direction of the sky, makes the task formidable. The resources available within the GSSS are:

- two PDS microdensitometers (Table 1)
- two VAX 11/750 computers
- a glass copy of the SRC-survey (Table 2)
- an advance copy of the SRC-J equatorial extension (Table 2)
- a "quick V" survey of the northern sky (Table 2)
- photoelectric sequences for each survey plate region (Table 3)

H. K. Eichhorn and R. J. Leacock (eds.), Astrometric Techniques, 721–727.

Details of the specific items are included in the tables referenced.

Table 1. Summary of characteristics of the GSSS PDSs

Platen size	50 x 50 cm
Density range	0 - 5 D
Base material	granite
Repeatability (note 1)	0.2 um
Accuracy over complete platen size (note 2)	0.6 um peak-to-peak
A to D converter	15-bit
Positioning	Hewlett-Packard interferometer
Maximum scan speed	190 mm/sec with lasers
Control computer	VAX 11/750

(1) based on scans of a 50 cm straight-edge (thin wire under tension)
(2) based on direct vs reverse tests of a grid of points over an area 35 x 35 cm

Table 2. Summary of characteristics of the GSSS survey plates

	ESO/SRC	SRC EXT	QUICK V
Sky coverage	-90 to -17	-17 to +3	+3 to +90
Telescope	UK Schmidt	UK Schmidt	Palomar
Plate Scale (arcsec/mm)	67.15	67.15	67.15
Plate size (cm)	35 x 35	35 x 35	35 x 35
Plate generation	copy	copy	original
Plate area (deg)	6.4 x 6.4	6.4 x 6.4	6.4 x 6.4
Plate center spacing	5 deg (1950)	5 deg (1950)	6 deg (1855)
Emulsion type	IIIaJ	IIIaJ	IIaD
Filter	GG 395	GG 395	Wratten 12
Limiting mag	22+	22+	19+
Epoch (mean)	1975	1983	1983
Total plates	606	288	584

Note: quick V plates taken after August 1984 with GG 495 filter

Table 3. Summary of characteristics of GSSS photoelectric sequences

Photometric accuracy	0.05 mag
Colors	B , V
Instruments	CTIO 0.6m, 0.9m Cloudcroft 1.2m (Sacremento Peak) Univ. of Arizona 1.0m
Stars per sequence (average)	6
Magnitude range (typical)	9.0 to 14.5
Spacing of sequences	one per plate (see table 2) within 0.5 deg square including 2 SAOC stars within 2.0 deg of plate center

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2. OPERATION OF THE GSSS

In order to give an overview of the way in which GSSS operates, consider the following steps in answering a guide star selection request for an ST observation:

(1) receive from the ST operations department the target position, date, ST roll angle, and the science instrument and aperture for the planned observation
(2) check to find what, if any, stars are available as possible guide stars
(3) find the magnitudes of the candidate guide stars
(4) find the positions of the candidate guide stars and the target
(5) based on positional accuracy, placement, ST requirements, etc, choose at least two guide star pairs
(6) send guide star information to ST operations

Steps (1) and (6) above are done with a data link between the GSSS and the Science Planning and Scheduling System (SPSS) within the ST ScI operations department. This is the only communications path to the outside world for the GSSS, and all requests and responses are sent through it.

Step (2), checking to find what stars are available in the region of the target as possible guide stars, involves constructing a portion of the Guide Star Catalog for the area of the sky near the target, producing a list of estimated positions and magnitudes for the possible guide stars from low resolution scans. The current plan of the GSSS is to scan all of the plate collection and produce the complete Guide Star Catalog (GSC) before launch, so that in general operation this step can be performed by searching the appropriate section of the catalog. The resulting list can be used to judge the feasibility of an observation as scheduled and provides a finding list for additional scanning for the position of the target or of special plates. If pointing the ST does not require high precision guide star positions, e.g. to point the wide field camera, the data in this list may be sufficient and steps (3) and (4) can be skipped.

If the Guide Star Catalog does not include the target or does not have the accuracy required for the observation, the plate will have to be rescanned at high resolution, including the target if visible. The photometric and astrometric calibrations, similar to those above but with higher intrinsic accuracy, will be done using the new scan data.

The photometric calibration (step 3) is done relative to the guide star photometric sequence (Table 3), a sequence of 6 stars in the range 9.0 to 14.5 visual magnitude for which the GSSS has obtained B and V photoelectric measurements. This sequence is near the center of the plate and near at least two SAOC stars for positional reference. The individual stars were chosen by estimated magnitude from visual inspection of the National Geographic Palomar Survey prints and the ESO/SRC film copies. The reduction of the photometric data in the center of the plate has an accuracy of about 0.15 mag. The correction of the results for the plate background and for the vignetting of the telescope, both problems of extrapolating the results from one

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sequence of stars in the center of the field to the rest of the plate, is a continuing area of research for the GSSS.

The positional calibration (step 4) uses the AGK3 or the SAOC as reference catalogs and (x,y) measurements determined from the PDS scan data using the "Supergauss" centroider, based on the work of Sanders and Schroeder (1980). The plate modeling and data reduction are being tailored specifically for ST purposes (Russell and Williams, 1986; elsewhere in these proceedings).

Step (5), the selection of the guide star pairs for the ST pointing from the available stars, is an area of the GSSS where the design and development is just beginning. What is needed is to program the priorities for the selection. These could include, for example, lower priority to those which are crowded by close neighbors and higher priority to those which are brighter. After launch the selection algorithm will be tuned, depending on the operating characteristics of the ST.

The scenario presented so far is for the general case, where the target and the guide stars are all measurable on one Schmidt plate. The case where guide stars must be chosen from separate plates will be handled by a plate overlap solution. The GSSS must also be prepared to handle special plates, including CCD images, which are provided by observers for targets which are not visible on the Schmidt survey plates. Another category is targets whose relative positions are not available from any photograph, for example radio sources or solar system objects. All of this will be handled by a GSSS production system which will process guide star requests as automatically as possible, requiring human operators only to handle the most difficult requests, to intercede when the automated system fails, or to handle plates.

3. GUIDE STAR CATALOG (GSC)

The GSC will be produced from low resolution scans of the Schmidt survey plates listed above, and processed to provide a catalog of the sky complete to 15th magnitude with the highest photometric and astrometric accuracy which can be obtained from that data using an automated system.

The scans will be performed using the PDSs with a 100 micrometer apodized aperture and 50 micrometer step size. Thus each plate will be converted to a 7000 x 7000 roster of digitized data. In crowded regions such as the galactic plane the scanning will be done with a 50 micrometer aperture and 25 micrometer step size.

The raw scan data is "inventoried" by an algorithm based on that used in the Cosmos program at Edinburgh (Lutz, 1979) to produce x,y positions and estimates of the image size, shape and integrated density for all objects on the plate to some programmable threshhold, probably low enough to include most stars to 16th magnitude. The inventory is "refined" by identifying blended images and finding improved positions using the Supergauss centroiding algorithm. The refined inventory is "classified" to identify galaxies and extended

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objects. The photometric and astrometric calibrations follow and are done with the Guide Star Photometry Catalog (GSPC) and the AGK3 or SAOC, respectively, as references. Finally the data are sorted, any objects in common with others already in the GSC are identified, the remainder are given GSC numbers, and the data merged to become part of the GSC.

In the first version of the catalog, the data for the stars which appear on more than one plate may be kept as separate entries with the same GSC numbers or a simple weighted mean may be taken. Later versions of the GSC are planned to have some global adjustment applied. That decision will be made after some experience is gained in the construction of the first version. To date about 200 plates (of the 1478 total) have been scanned, and the algorithms for the photometric and astrometric data reduction, as well as the inventory and centroid algorithms, are all in the latter stages of testing. The planned accuracy of the Guide Star Catalog is at least 1 arcsec in position and 0.4 mag in the bandpass of the plate. Preliminary tests show that at least the astrometric accuracy may be better than this. Every gain in the accuracy of the catalog makes the GSC more useful to the GSSS operations and also to the astronomical community.

Initially all of the data files generated in the construction of the catalog will be archived on magnetic tape. At least three of these files will be permanently archived -- the raw scan data, the complete inventory of the plate before eliminating blends, and the classified calibrated inventory, the last file before integration into the GSC. These provide most of the information lost in the processing without rescanning the plate. And the GSC is designed such that new plate solutions easily can be incorporated into the catalog to replace or refine old ones.

The first version of the Guide Star Catalog will be completed around the time of the ST launch in mid-1986 and will be kept on line at the ST ScI. Publication is planned after launch, with a printed description and the catalog itself in machine readable form. One of the major decisions in the catalog construction is the method to be used for star identification, one which allows efficient access to the catalog entries and minimizes the amount of disk space needed. The method chosen uses the sky divided into regions and the stars simply numbered sequentially within them. These regions will be about 20,000 in number and thus should each contain about 2000 stars, or the total catalog is projected to contain up to about 40 million stars. The regions will be defined initially as rectangles on the sky, whose boundaries are lines of constant right ascension and declination. To maintain some uniformity in the number of stars contained in each, they will not all be the same size; the width of the regions within a given declination band will vary with galactic latitude to allow for varying star density. Star numbers within a region will not be ordered with either coordinate because of the method of construction. Star numbers within the GSC are permanent; stars will not lose their designation if improved positions would otherwise move them out of the area defined originally as the region. Thus each region will have limits which overlap slightly adjacent ones.

We realize from the interest of the astronomical community already that the Guide Star Catalog will be a valuable resource beyond the use at ST; however we note in advance of its completion that the catalog is being constructed with its major requirement the planned use of it for ST, not as a general catalog. We caution prospective users to be familiar with its construction, structure and accuracies, both internal and external, before using it for any purpose other than that for which it was constructed. Even with this restriction, its uses beyond pointing and scheduling the ST will be myriad. One example is that a portion of it will provide the input catalog for the Tycho data reduction, and many new uses will be found.

4. FURTHER INFORMATION ON THE GUIDE STAR SYSTEM

As the construction of the Guide Star Selection System continues, we plan a number of publications to allow our colleagues from outside the ST project to follow the progress in the construction. The PDS design enhancements and initial tests have been published by Kinsey, etal. (1984). The overall Guide Star Selection System has already been described in a number of IAU symposia and other proceedings and will continually be updated in the same manner. The photometric and astrometric test results and algorithm descriptions will be published in the refereed literature. Some news of the GSSS will be included in the ST ScI newsletter, which is sent out quarterly. The publication of the Guide Star Photometry Catalog should take place within the next two years. The publication of the Guide Star Catalog should follow within a year the launch of the Space Telescope.

5. ACKNOWLEDGEMENTS

A project this size of course is the work of a large team working together. It is appropriate to acknowledge here several of the major contributors to the Guide Star Selection System: Barry Lasker, project scientist, who has been responsible for the photometry and inventory algorithmic development as well as the first overall design of the GSSS; Bruce Gillespie, project manager, who has handled the programmatic management responsibilities; Helmut Jenkner, project leader, who is in charge of the project during integration of the algorithms with the software and hardware; James Kinsey, former project engineer, who did the integration of and enhancements for the PDSs; Marc Damashek, PDS team leader, who has charge of the current development/maintenance of the PDSs.

6. REFERENCES

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Discussion:

EICHHORN: It is interesting to compare 30×10^6 stars per six collaborators with 4×10^6 stars in the AC per 10^2 collaborates. The comparison of precision per collaborator is most impressive.

HØG: Could you give a figure for the degree of completeness in the range 10^m to 12^m?

RUSSELL: The estimate of the size of the guide Star Catalogue range from 20 to 30×10^6 stars. The latter of these values probably is closer to the truth. The completeness of the catalogue to 12^m should be 100% in sparse fields. We have just begun testing in crowded fields. I would estimate that in crowded fields, our completeness in this magnitude range will be at least 95%.

WESTERHOUT: I recommend that you name your "guide star constellations" or bins in a manner that makes it somewhat easy to find out approximately where they are located in the sky.

RUSSELL: First we have to decide how to define the regions - by plate, by right ascension and declination, by galactic coordinates, or by some other method. I hope that we can use right ascension and declination since most targets will be given in those coordinates. I will carry along your suggestion to the complete guide star selection committee.

MURRAY: Will you be able to measure the fiducial marks on the SRC survey plates, so that your coordinates will be related to the published survey charts for the southern hemisphere?

RUSSELL: Right now, our notice of the fiducial marks on the SRC plates is to make sure we eliminate them in our inventory processing and do not list them as astronomical objects.