The Guide Star Selection System for Space Telescope

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Abstract

A facility capable of automatically selecting guide stars for Space Telescope is described, which, as presently envisioned, consists of two microprocessor-controlled high speed microdensitometers, a central processing computer, an extensive plate library, and a large, continually evolving data base, all to reside at the Space Telescope Science Institute.

Introduction

The NASA 2.4 meter Space Telescope[1], to be launched by Space Shuttle in late 1983, will operate unattended for most observations. The pointing and control system is comprised of three interferometric Fine Guidance Sensors, with access to an outer annulus of the telescope field of view as shown in Figure 1. Target acquisition is accomplished by pointing the ST at the approximate location of the target object, locating guide stars in the field of view accessible to Fine Guidance Sensors, and then utilizing the known relative positions of guide stars and target to place the target on the acquisition aperture of a Scientific Instrument (SI). Positional accuracies involved are determined by the smallest acquisition aperture of the several SIs. For the first set of instruments to be flown, 1-σ positional accuracies of better than 0".33 are required. Since automatic target acquisition will require advanced knowledge of the brightness (to within 0.5 magnitude) and relative positions of guide stars and target objects and since complete catalogs of these values are nonexistent for stars of the magnitudes required for ST guide stars ($9 \leq M_V < 14.5$) we have devised a Guide Star Selection System (hereafter, GSSS) based in part on Inventory procedures developed by us for occultation prediction[2] and the generation of secondary positional standards for the measurement and reduction of small scale astrometric plates.[3] An outline for an early design of the GSSS can be found in Benedict and Shelus[4].

In addition to choosing guide stars, this system will also have the task of determining precise positions for Astrometry targets to be observed with any one of the three Fine Guidance Sensors, since they will be used as the Astrometry "SI" and lack imaging capability.

This design has been supported by Space Telescope through our participation in the Astrometry Team and has greatly benefited from numerous discussions with the other members of that team: W. Jefferys, Principal Investigator; P. Hemenway; R. Duncombe; W. van Altena; L. Frederick; and O. Franz.

A fully realized Guide Star Selection System may well rely on other recent software innovations including: digital centering[5,6], automated inventory, [4,7,8], object discrimination[9,7] shape classification[10], and digital photometry[11,12]. The following paragraphs describe one solution to the problem of providing to Space Telescope the required positional and brightness information for guide stars. A much more detailed description can be found in Benedict.[13]

The Solution

Software. Let us assume that on a photograph a region of sky somewhat larger than the focal plane of ST has been inventoried, providing a list of positions and magnitudes of potential guide stars suitable for an observation of a particular target with ST on a particular date. What steps are necessary to obtain this list to the required 1σ accuracies, 0.33 arc second for position, 0.5 magnitude for brightness? In modern software terms each step is called a filter.[14] Filters are simple programs that read a standard input, make useful changes to the data and write a standard output. We pass the data through the following series of filters.

Objects are found on a plate above some detection threshold. This is the inventory process. Precise relative positions are determined for these objects via digital centering. Brightnesses are determined for the located objects using the techniques of digital photometry. Galaxies and close double star pairs are removed from the list using object discrimination and shape classification algorithms.

Next, because recent epoch plates will in general not be available to the GSSS, accurate relative positions of guide stars for the epoch of observation will be provided by measuring two plates taken as far apart in time as possible, determining proper motions of the objects and extrapolating to the epoch of observation. This filter will also eliminate plate flaws, which would show up as stars of absurdly large proper motion. At this point relative positions are transformed into absolute positions by referencing stars with known absolute positions. These standard stars are measured just before or after an inventory is completed.

With our list of possible guide stars a last set of filters are applied. Do stars of the proper brightness fall within the Fine Guidance Sensor access areas (Figure 1) when the target sits on the required SI aperture? Are there stars within some angular distance of potential guide stars with brightnesses within some magnitude range of the potential guide stars? If so, these must be deleted from the list. Can we maximize the separation of a chosen set of guide stars and hence minimize problems with spacecraft roll stabilization? For moving targets, can a series of guide stars be chosen such that the object can be viewed for the required length of time along its path? If no guide stars are available for a specific time of observation, can a set be made available by changing the roll of the spacecraft from some nominal value? Will a set become available at some future date? This is not as foolish a question as it looks. The $+V_3$ vector in Figure 1 must generally point at the sun to maximize power from the solar arrays. The sun moves relative to the stars and so the roll orientation of the focal plane relative to the stars changes with time. This list is not exhaustive. The goal of the GSSS software development effort will be to implement automatic versions of these filters while giving the system operators selection status information at each step and veto power over any step.

The order in which these many filters are applied has not been finalized. Indeed, the first two steps may be merged into a single step depending on final hardware considerations.

Hardware. The primary design considerations when selecting the hardware for the GSSS are measuring speed and accuracy. Present studies of the expected efficiency of ST require the GSSS to produce between 15 and 25 sets of guide stars each working day (2 shifts, 5 days per week). In addition, a design goal is to insure that the entire selection process take less than one hour for a "target of opportunity" such as a galactic supernova event. The over ten years experience with a PDS microdensitometer by one of us (GFB) and a number of evaluations by members of the astronomical community (e.g.[6]) indicate that a Perkin-Elmer PDS 2020G (microprocessor equipped) is suited to the required task. Proper motion determination requires two independent measurements. To allow the GSSS to keep up with the consumption of GS on board Space Telescope, we envision two PDS 2020G microdensitometers working in parallel. Each will be microprocessor controlled, operate independently, and each will communicate data to a VAX 11/780, the central processing computer for the GSSS. The expected complexity of the output graphics containing, for example, star position, proper motion and brightness data, Fine Guidance Sensor access area outlines, Science Instrument aperture sizes and locations, spacecraft roll parameters, and sun, moon and earth limb angular distances and position angles will necessitate a high resolution color graphics terminal and a high quality color hard copy facility.

Plate Library. The selection of the sets of wide field photographic surveys which will reside in the GSSS plate library was determined by the results of a study undertaken by the Astrometry Team[15]. The requirements of sky coverage, limiting magnitude, plate scale and epoch of observation (a more accurate proper motion, hence, position will be determined with a longer time baseline between the measured pair of plates) lead us to the following list of surveys: Lowell and Lick for regions north of the equator; Bruce and Luyten down to -20° declination; Bruce and SRC(J) or ESO(R) south of -20° declination. To provide high fidelity glass copies of these six surveys would be very expensive. Recent tests[16] indicate that film copies would provide astrometric quality, but the long term stability of film has not been exhaustively tested. The plate library should not be committed to film until we are reasonably sure that fifteen years of use will not degrade the astrometric performance.

Wide-field plates are generally quite large (30-50 cm on a side), a consideration which also contributed to the choice of the P-E 2020G microdensitometer. It has a 50 x 50 cm clear scanning area.

The plate material and hardware selected for the GSSS insure the positional accuracy needed by ST, but do not insure by themselves the required photometric accuracy. Most wide field survey material is uncalibrated. To obtain stellar photometry from this material requires that magnitudes be known for a number of stars with a magnitude range $15>V>9$ found on each plate. This is called a photometric sequence. Franz[17] has determined that fewer than 25 percent of the plates to be used by the GSSS contain already observed photometric sequences. For the GSSS to meet its magnitude specification, a number of sequences will have to be observed, perhaps most efficiently (for the Northern Hemisphere) by an automatic telescope such as the Cloudcroft 122 cm.[18] This set of sequences would have great utility for all of Astronomy, not just for Space Telescope.

Expected Performance

For each new target to be observed with ST, the GSSS will perform an inventory and produce a list of candidate guide stars. The absolute positions of the guide stars will be known only as well as the reference stars used in the astrometric solutions, generally 0.3-0.5 arc seconds. The relative positions will be known to better than 0.33 arc seconds. For targets requiring guide star-target relative positions of much higher accuracy, special plate material will be required. To obtain the highest accuracy, this plate material will need to be recent with a very small scale. As an example, a recent, properly exposed McDonald 82" cassegrain camera plate covers a region of the sky 25 x 31 arc minutes and has a scale of 7.33 arc seconds per millimeter. From such a plate and through the use of sophisticated centering algorithms we could hope to extract image centers with about 2μ accuracy to obtain relative guide star-target positions of about 0.015 arc seconds.

As previously mentioned, this system should be capable of producing 15-25 sets of guide stars per working day. This figure would drop if only a single PDS 2020G was available. The second machine serves a number of purposes. It guarantees an ability to keep up with guide star consumption aboard ST. It provides for a back-up capability in the event of malfunction of either PDS. Finally, having a device capable of digitizing plates of general astronomical interest in support of ST operations could further enhance the quality of science generated by ST. Having two microdensitometers insures there being time for such projects.

There are a few remaining problems associated with the Guide Star Selection System. It remains to be demonstrated that star/galaxy discrimination can be carried out on copies of original plate material. Copies generally compress the density range of the original and may present problems for the discriminants presently available.

A remaining software problem is that of locating for the GSSS a data base management system of sufficient power. An arbitrary inventory process will occasionally remeasure stars. How will these data be merged with the data file of potential guide stars? What will be the organization of such a file? Can high speed searches of this file for previously inventoried fields be made? How will data from Space Telescope concerning the quality of Guide Stars (was one a double star, or a variable, or had an erroneous predicted position?) be merged with the data base? More importantly, vastly more accurate relative guide star-target positions can be obtained from ST simply because a successful observation was made. The interface between ST operations and the GSSS to effect this data transfer is still being defined.

Summary

A system capable of providing guide stars for Space Telescope has been described. It consists of a pair of P-E 2020G microdensitometers. These are microprocessor equipped and will each scan independently. The needs for proper motion information, adequate throughput of the system, and some amount of general plate digitization dictate two such devices in the system. They will communicate with a central VAX 11/780 which will handle the final selection process once the inventories are completed.

Both the inventory and final selection processes will probably include a number of recent algorithms allowing automatic digital entering, inventory, shape classification, object discrimination, and digital photometry to be carried out on photographic plates.

An important element of the GSSS will be a large plate library containing three pairs of wide field surveys covering the entire sky at two different points in time, again dictated by the need for proper motion information.

Finally, the GSSS data base will contain large files of information on potential guide stars, successfully used guide stars, Astrometry targets, and various catalogs of astrometric and photometric information.

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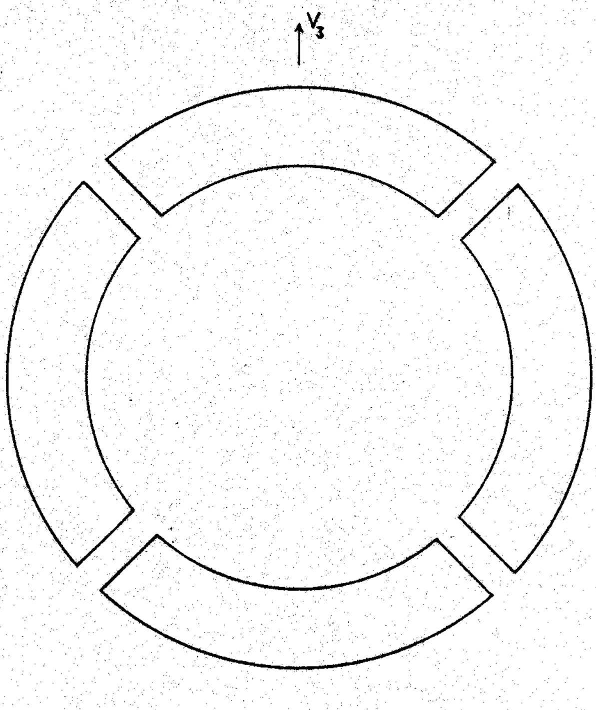

Figure 1. Space Telescope Focal Plane. The focal plane of Space Telescope contains three areas accessible to the Fine Guidance Sensors, the area nearest the $+V_3$ axis and those to either side. Due to the necessity of providing the solar array with as much sunlight as possible, the $+V_3$ axis generally lies in a plane containing the sun and the target. The Fine Guidance Sensors have a field of view of one arc second. Initial guide star acquisition will require moving them in a spiral search pattern which can be as large as 1.5 arc minutes.